
Energy audit and inspection procedures

T50.C4

A Technical Report of IEA SHC Task 50

April 6th, 2016



IEA Solar Heating and Cooling Programme

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Energy audit and inspection procedures

A Technical Report of Subtask T50-C4

IEA SHC Task 50: Advanced Lighting Solutions for Retrofitting Buildings

2016-04-06

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KEYWORDS

Daylight availability & Daylight glare metrics, Benchmark on case study

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PREFACE

Lighting accounts for approximately 19 % (~3000 TWh) of the global electric energy consumption. Without essential changes in policies, markets and practical implementations it is expected to continuously grow despite significant and rapid technical improvements like solid-state lighting, new façade and light management techniques.

With a small volume of new buildings, major lighting energy savings can only be realized by retrofitting the existing building stock. Many countries face the same situation: the majority of the lighting installations are considered to be out of date (older than 25 years). Compared to existing installations, new solutions allow a significant increase in efficiency – easily by a factor of three or more – very often going along with highly interesting payback times. However, lighting refurbishments are still lagging behind compared to what is economically and technically possible and feasible.

IEA SHC Task 50: Advanced Lighting Solutions for Retrofitting Buildings” therefore pursues the goal to accelerate retrofitting of daylighting and electric lighting solutions in the non-residential sector using cost-effective, best practice approaches.

This includes the following activities:

- Develop a sound overview of the lighting retrofit market
- Trigger discussion, initiate revision and enhancement of local and national regulations, certifications and loan programs
- Increase robustness of daylight and electric lighting retrofit approaches technically, ecologically and economically
- Increase understanding of lighting retrofit processes by providing adequate tools for different stakeholders
- Demonstrate state-of-the-art lighting retrofits
- Develop as a joint activity an electronic interactive source book (“Lighting Retrofit Adviser”) including design inspirations, design advice, decision tools and design tools

To achieve this goal, the work plan of IEA-Task 50 is organized according to the following four main subtasks, which are interconnected by a joint working group:

Subtask A: Market and Policies

Subtask B: Daylighting and Electric Lighting Solutions

Subtask C: Methods and Tools

Subtask D: Case Studies

Joint Working Group (JWG): Lighting Retrofit Adviser

ABSTRACT

This document consists of three parts dealing with energy audit and inspection procedures

The first section (*2.1: Daylight performance assessment methods*), deals with the description of the different metrics available to evaluate the daylight contribution.

These metrics are distinguished in two categories: Daylight availability metrics and daylight glare metrics. For each of them, a short description is given, followed by an example. Then comes a paragraph describing the boundaries of the metric and some references.

The topic of the second section (*2.2 Investigation of energy monitoring procedures for electric lighting systems*) is addressed in detail within the framework of subtask D (*Case-studies*). This chapter does not intend to report on this work, but simply focuses on the presentation of a “flash” analysis method used in Switzerland to assess the lighting status of existing buildings.

This simple method, based on a quick tour of the building, is used as a kind of checklist. Insofar as it does not include detailed monitoring (only a few punctual illuminance measurements) it does not intend to draw a detailed view of the situation but aims to identify the potential actions for lighting refurbishment.

In the third section (*2.3 Benchmark on case-study*) we show, for the different metrics, the results obtained by the simulation tools described in C-2 document. The case study corresponds to the “*After Refurbishment*” situation described in C2 document (*cf. C2.6.1 Description of the case study for lighting simulations*).

EXECUTIVE SUMMARY

Energy audit procedures should be used in buildings before and after refurbishment to evaluate the benefits of lighting retrofit strategies. Monitoring of the daylight performance of buildings using the appropriate metrics as well as the assessment of lighting power densities and electricity consumption (energy monitoring) should be carried out in a standardized way. Long term as well as short-term procedures shall be considered. Inspection procedures should document the status of a lighting installation considering for instance the maintenance situation, electrical status, lighting quality provided (levels, glare etc.). This documents consists in three sections:

The first section (*2: Metrics*), deals with the description of the different metrics available to evaluate the daylight contribution.

These metrics are distinguished in two categories: daylight availability metrics and daylight glare metrics. For each of them, a short description is given, followed by an example. Then comes a paragraph describing the boundaries of the metric and some references.

The topic of the second section (*3: Energy monitoring procedures for electric lighting systems*) is addressed in detail within the framework of subtask D (*Case-studies*).

This chapter does not intend to report on this work, but simply focuses on the presentation of a “flash” analysis method used in Switzerland to assess the lighting status of existing buildings.

This simple method, based on a quick tour of the building, is used as a kind of checklist. Insofar as it does not include detailed monitoring (only a few punctual illuminance measurements) it does not intend to draw a detailed view of the situation but aims to identify the potential actions for lighting refurbishment.

In the third section (*4: Benchmark on case-study*) we display, for the different metrics, the results obtained by the simulation tools described in C-2 document. The case study corresponds to the “*After Refurbishment*” situation described in C2 document (*cf. C2.6.1 Description of the case study for lighting simulations*).

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1. INTRODUCTION

Energy audit procedures should be used in buildings before and after refurbishment to evaluate the benefits of lighting retrofit strategies. Monitoring of the daylight performance of buildings using the appropriate metrics as well as the assessment of lighting power densities and electricity consumption (energy monitoring) should be carried out in a standardized way. Long term as well as short-term procedures shall be considered.

Inspection procedures should document the status of a lighting installation considering for instance the maintenance situation, electrical status, lighting quality provided (levels, glare etc.).

This document presents the most common metrics used to evaluate lighting performance. It begins by describing the most common one (daylight factor), continues with the different metrics that integrate climatic data (daylight autonomy) and, finally, ends with metrics relating to visual comfort. Other daylight visual comfort metrics or evaluations (like view to the exterior, color rendering, color of light, non-visual effects...) are either not implemented in available tools or are still under development. The descriptions were made by the experts involved in this IEA-50 task.

Daylight availability metrics

The daylight availability metrics try to quantify the amount of daylight reaching a space. This amount depends not only on façade construction and obstruction, but also on occupation, location, climate and orientation. To quantify the overall (=annual) amount of daylight, the metric should be able to account for these parameters.

The metrics fully accounting for this are: the daylight autonomy DA, spatial daylight autonomy sDA, the continuous daylight autonomy DAcon and the useful daylight illuminance UDI. They are based on hourly calculation of the horizontal illuminance and consider direct and diffuse irradiation from a weather data file, as well as the use of shading devices according to a pre-defined algorithm and the presence of occupants according to a pre-defined schedule.

A simplified approach is the calculation of the relative luminous exposure. It describes the fraction of daylight, fulfilling an illuminance threshold value throughout the year. The simplified method correlates the daylight factor calculation to the relative luminous exposure and corrects for different façade/shading systems, as well as for orientation and climate.

Another simplified approach to quantify the annual daylight availability is used by the diffuse daylight autonomy. This method calculates the hourly illuminance levels considering only the diffuse irradiation. The usage of shadings is not considered assuming the shadings are only activated in case of direct sunlight exposure and should be designed to allow enough daylight when exposed to direct sunlight.

Some of the available tools claim to calculate the daylight autonomy while they are only supplying a simplified version of the diffuse daylight autonomy. It is, for example, the case of the software ECOTECT. User should thus be careful and should check the calculation algorithms used by the tool they use.

The daylight factor method is a purely static method describing the fraction of daylight in a space under overcast situations. It does not consider the contribution of the sun, the influence of climate, latitude and orientation as well as the use of shading devices.

Some metrics (maximum daylight autonomy, annual sunlight exposure and UDI exceeded) try to quantify excessive penetration of daylight. Their purpose is to describe discomfort like

glare, too high contrast or overheating. Since all these metrics are based on the calculation of horizontal illuminance values only, it can be questioned if these metrics are suitable to describe visual discomfort. Therefore the interpretation of these values has to be done very carefully and adapted to the investigated space.

Visual comfort metrics

The paper presents the two most common metrics that are used to quantify the visual comfort of the occupants, namely, the Daylight Glare Index (DGI) and the the Daylight Glare Probability (DGP).

For each metric, the information is presented as follows:

- Short description,
- Example
- Limits
- References
- Tools calculating the metric.

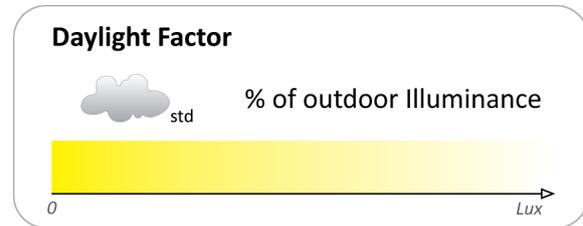
As some of the presented metrics are really specific and not very intuitive, this document is mostly dedicated to experts.

2. METRICS

2.1. Daylight availability metrics

2.1.1. Daylight factor

Source: B. Paule / Estia SA, Switzerland



Short description

The **daylight factor** (%) is the ratio of internal light level to external light level and is defined as follows :

$$DF = E_i/E_o \cdot 100.$$

Where E_i = indoor illuminance, E_o = Outdoor illuminance.

The reference sky used for daylight factor calculations is Standard CIE overcast sky.

The typical values for DF can be analyzed as follow:

- $DF < 2\%$: the influence of daylighting is low and the corresponding area is not adapted for permanent workplaces.
- $2\% < DF < 5\%$: the influence of daylight is sensible and the corresponding area will take benefit from daylight up to 50% of the working hours.
- $DF > 5\%$: the influence of daylight is high and the corresponding area will be self sufficient during more than 50% of the working hours, but glare problems may occur.

Most standards dealing with environmental quality and energy efficiency, such as LEED, BREAM, CERTIVEA or DGNB, rely on daylight factor values (DF).

Classification (DF = Daylight Factor)	Daylight Penetration (Access of the zone to daylight)
$DF \geq 3\%$	Strong
$3\% > DF \geq 2\%$	Medium
$2\% > DF \geq 1\%$	Weak
$DF < 1\%$	None

Table 1: Daylight penetration as a function of the Daylight Factor (D) [3]

Example

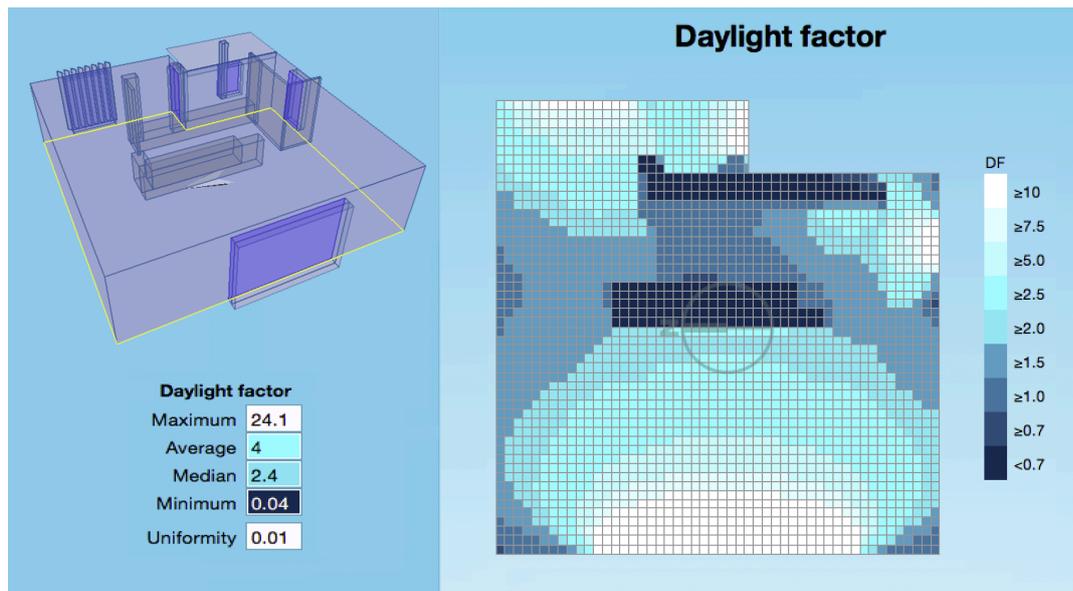


Figure 1 Example of daylight factor analysis (Simulation DIAL+Lighting).

Limits

This approach does not take into account the direct component and is not sensible to climate and orientation. Furthermore, DF is not an intuitive notion and may hardly be used by non-specialists.

References

- 1 ASE, Association Suisse des Electriciens Eclairage intérieur par la lumière du jour Association Suisse des Electriciens, Norme Suisse SN 418911, Zürich, 1989
- 2 CIBSE Lighting Guide 10: Daylighting and window design, Year: 1999, ISBN 0-900953-98-5
- 3 PrEN 15193: Energy performance of buildings — Energy requirements for lighting, CEN/TC 169, 2006.

2.1.2. CIE Curves

Source: B. Paule / Estia SA, Switzerland

Short description

The CIE Curve method gives an indication of the outdoor diffuse illuminance availability according to the latitude [4].

Example

Figure 2 below shows that the outdoor diffuse horizontal illuminance exceeds 8000 lux during 85% of the time (between 9AM and 5 PM) for a 45° latitude.

Thus, for a 5% daylight factor this chart indicates that the corresponding illuminance exceeds 400 lux during 85% of the period.

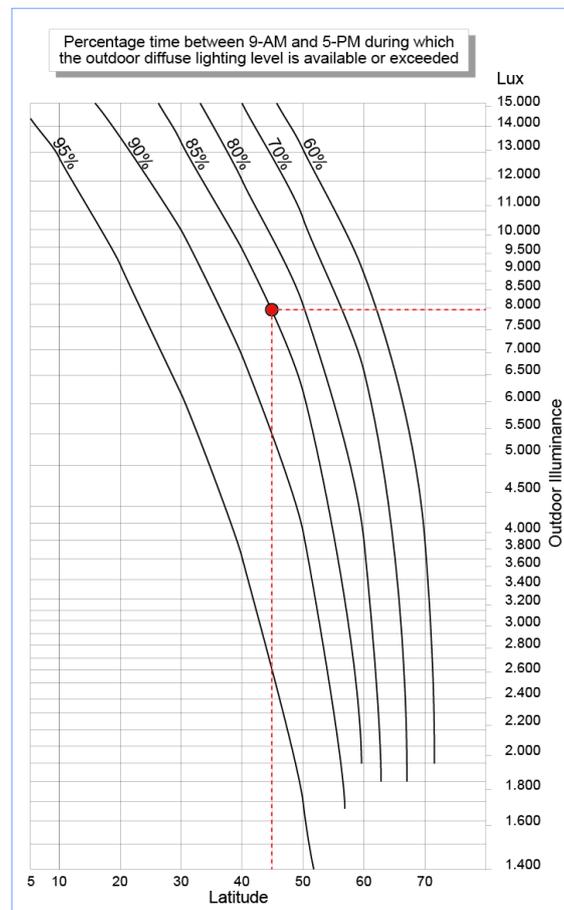


Figure 2: CIE chart: Outdoor diffuse illuminance availability as a function of the latitude

Limits

This approach does not take into account the direct component and is not sensible to orientation.

References

4 CIE. Daylight. CIE-16. Vienne: Commission Internationale de l'Eclairage, 1970, 79 p.

Tools calculating this metric

NA

2.1.3. ASE-SLG Chart

Source: B. Paule / Estia SA, Switzerland

Short description

A first attempt to make a link between daylight factor values and the coverage of lighting needs was proposed in 1989 by the Swiss Association of Electricians (ASE-SLG) [5]. This approach is available for the Swiss climate and only deals with overcast sky conditions.

Example

Figure 3 below shows that according to this method, a 5% DF leads to cover 50% of the lighting needs if the required illuminance is 500 lux.

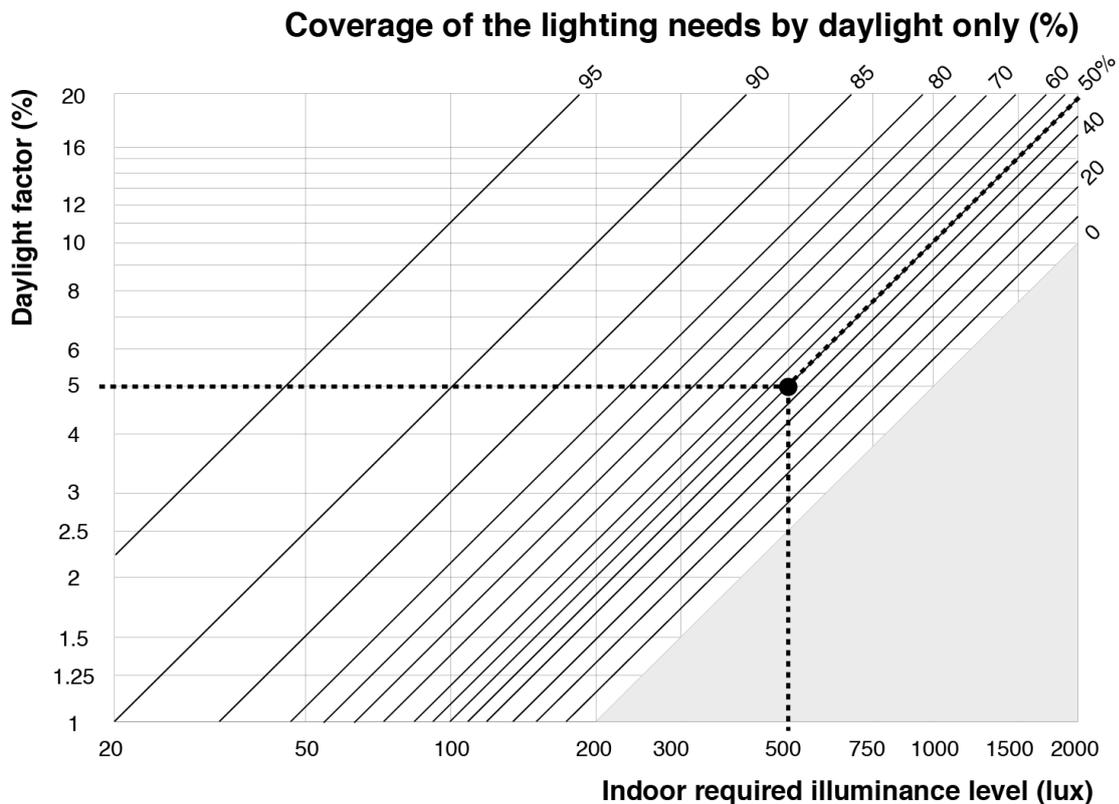


Figure 3: SLG-ASE chart : Coverage of the lighting needs by natural light, as a function of the indoor illuminance level and the daylight factor value. Period: 7.00 -17.00 in winter, and 8:00 -18:00 in summer (sun hours), overcast sky conditions.

Limits

This method is only taking into account overcast sky conditions for Switzerland. Furthermore, it does not consider the orientation of the room.

References

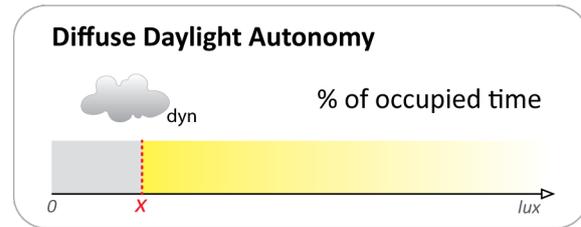
- 5 ASE, Association Suisse des Electriciens Eclairage intérieur par la lumière du jour Association Suisse des Electriciens, Norme Suisse SN 418911, Zürich, 1989.

Tools calculating this metric

NA

2.1.4. Diffuse Daylight Autonomy

Source: B. Paule / Estia SA, Switzerland



Short description

This concept was developed in the European Project DIAL-Europe (1999-2002) [6]. The principle is to use climatic data of the building location, to translate the daylight factor value into a new metric aiming to estimate the percentage of time during which the required level of illumination will be achieved thanks to daylight.

Diffuse Daylight Autonomy (also referred to as Diffuse Daylighting Autonomy) is based on hourly meteorological data which are processed using the Perez [7],[8] model in order to calculate:

- The hourly value of outdoor horizontal diffuse illuminance.
- The hourly value of inclined diffuse illuminance.

The diffuse daylight autonomy (DDA), weighed by orientation factors, is then calculated for the opening hours, according to the method described by Paule & al [9].

Once daylight factor values are calculated, the additional calculation time to obtain DDA values is very short (2-3 seconds).

One of the advantages of this metric is that it allows to estimate the annual electricity consumption due to electric lighting. For example, if the average DDA of a given room is 64%, then the percentage of time during which the lamps will be switched on can be estimated to 36% of the opening hours.

Example

Figure 4 hereafter shows an example of the distribution of Diffuse Daylight Autonomy on the workplane in a given room namely fitted with one or two glazed facades.

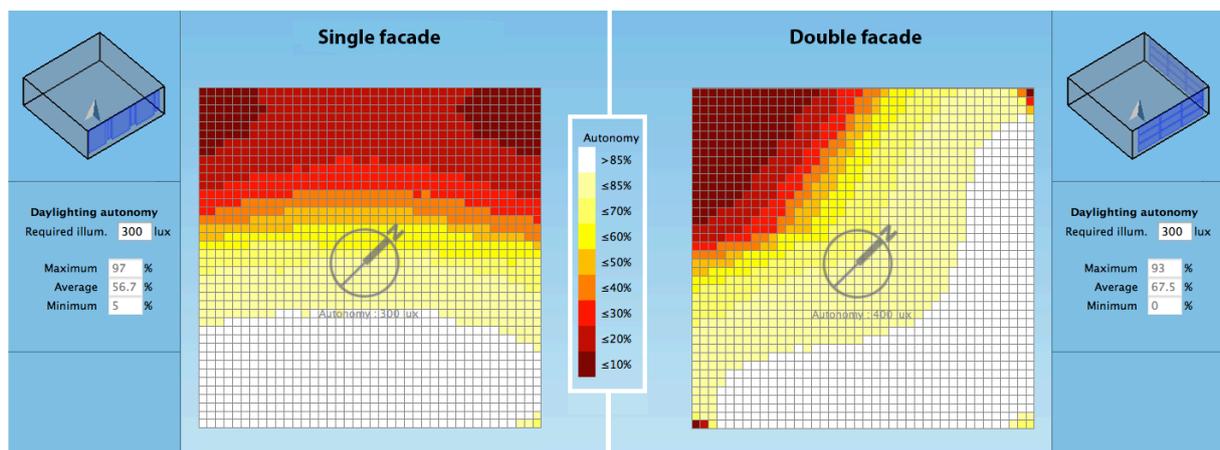


Figure 4: Examples of Diffuse Daylight Autonomy distribution (DIAL+Lighting simulation)

DDA is highly dependent on the room orientation and the building location (latitude is a major factor). As far as it is based on the required illuminance, DDA is also linked to the room function.

Figure 5 shows that, for a classroom located in Milano (Lat. 45°N), a 52% average DDA is considered as “Average” to “Good” if the room is South-East oriented and “Good” to “Very Good” if the same classroom is facing North-West [10].

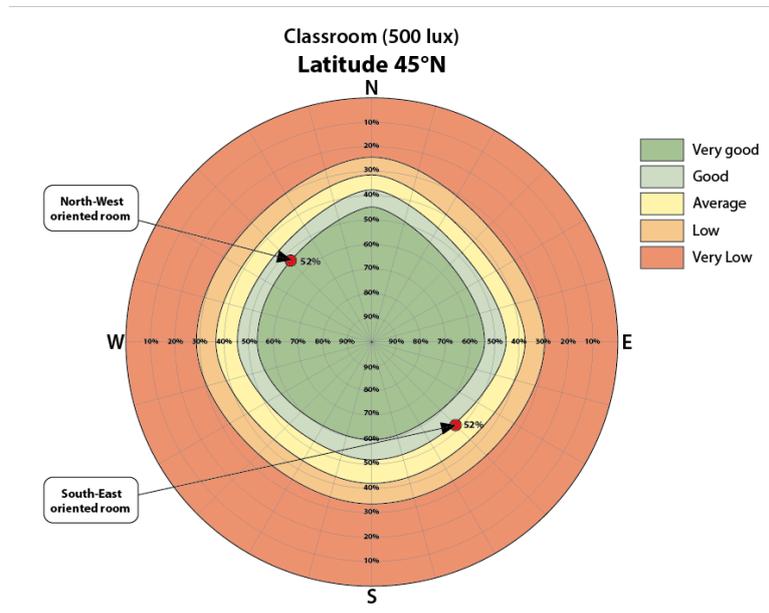


Figure 5: Example of targets for Diffuse Daylight Autonomy of a “Typical” classroom, for latitude 45°N

The “*Very good*” class corresponds to a room with a “largely but not fully” glazed façade and « *Very low* » corresponds to a situation where the windows to floor ratio (WFR) represents 1/6 of the room surface area. The “*Good*”, “*Average*” and “*Low*” classes are intermediate stages evenly distributed between the lower and upper limits [10].

Limits

This metric does not take into account the sun contribution. However, since many studies have shown that the use of shading devices is quite unpredictable, it seems acceptable to rely on outdoor diffuse illuminance to estimate with reasonable confidence the daylight contributions to indoor lighting. Furthermore, in many cases, when the sun hits the façade appropriate shading devices allow to block the direct radiation without obscuring the room and thus, do not result in the ignition of lamps.

References

- 6 Paule B et al: “DIAL-Europe: An European Integrated Daylighting Design Tool “, Proceedings of the PLEA -2002 conference, Toulouse, France, July 2002.
- 7 Perez R, Seals R, Ineichen P, Stewart R, Menicucci D: “A new simplified version of the Perez diffuse irradiance model for tilted surfaces” *Solar Energy* 39 (3), 221–232, 1987.
- 8 Perez R, Ineichen P, Seals R, Michalsky J, Stewart R: “Modeling daylight availability and irradiance components from direct and global irradiance” *Solar Energy* 44 (5), 271–289, 1990.
- 9 Paule B, Bouvier F, Courret G: « Eclairage naturel », *Techniques de l’Ingénieur*, CC 3315, Fév. 2008.
- 10 Paule, B & AI, “Diffuse Daylighting Autonomy: Towards new targets”, Proceedings of the CISBAT’13 Conference, Lausanne, Switzerland, Sept. 2013.

Tools calculating this metrics

- DIAL+Lighting
- Geronimo

2.1.5. Dynamic Daylight Autonomy

Source: M. Bodart
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Short description

In 2001, Reinhart and Walkenhorst redefined the daylight autonomy as “the percentage of the occupied time of a building, over a year, during which a minimum is achieved only by natural light” [11].

Two kinds of daylight autonomy are distinguished: the static and the dynamic ones. The static daylight autonomy is based on the evaluation of the daylight factor at the point considered and then takes into account only the overcast sky conditions. It does not consider the sunny or intermediate skies, nor does it consider the use of shading devices. By cons, the dynamic daylight autonomy is based on the prediction of the illuminance at the point considered at each time step (on hourly or less) over the year. The illuminance is then predicted from the weather file.

Later, the dynamic daylight autonomy has been completed by combining with models that predicted the status at each time step of the manual control of solar protections. This notion is then called the “effective” dynamic daylight autonomy [12]& [13].

Related metrics

Continuous Daylight Autonomy (DA_{con})

Defined by Rogers in 2006 [14]: a partial credit is granted when the illuminance is under the minimum level required. This metric highlights the beneficial contribution of natural light even at low level.

Maximum Daylight autonomy (DA_{max})

The maximum daylight autonomy is defined as the percentage of occupied hours during which the direct sun enters the buildings or excessive daylight levels are achieved.

The maximum level is fixed with respect to the objective set for the daylight autonomy. It is 10 times this value (ea: if the level objective of the DA is 300 lux, the maximum level will be 3000 lux). This manner to fix the maximum value is the weakness of this metrics because it is intuitive instead to be based on experimental research.

Example

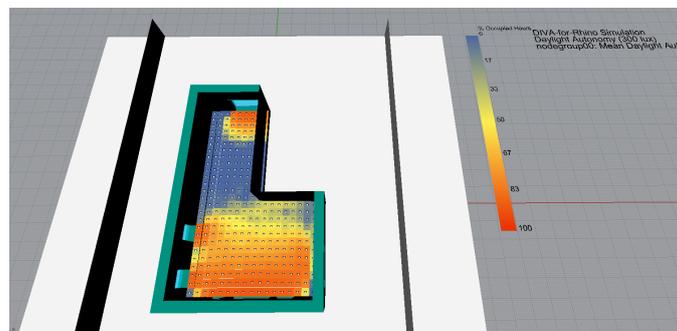
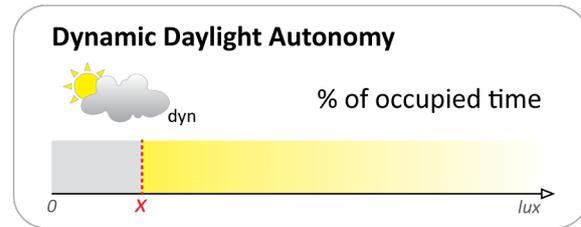


Figure 6: Example of Daylight Autonomy (for 300 lux)



Goal values

The use of the DA metric is recent; however some authors defined targets values. These targets have to be deeply studied and adapted in order to consider the climate of the site.

Daylight autonomy:

Rogers criteria [14]:

- Spaces that achieve a DA between 40% and 60% over more the 60% of their surface have the base credit
- Spaces that achieve a DA between 60% and 80% over more the 60% of their surface have the additional credit
- Spaces that achieve a DA more than 80% over more the 60% of their surface have two additional credits.

Reinhart & Walkenhorst criteria [11] :

Half of the DA of an exterior point not shaded with the same occupancy profile for this particular climate. Then, a space is considered lit naturally if it receives at least half time enough natural light, compared to an external point.

Maximum daylight autonomy:

Rogers criteria [14] :

Not more than 5% of the space can have a DAm_{ax} greater than 1% [14].

Limits

As this metric is climate based, it is supposed to be the more accurate to evaluate the daylight availability in a building. However, as the result of a whole year calculation is aggregated into one single value, the temporal evaluation of daylight is somehow lost.

Another limitation is due to the fact that the simulation results are supposed to model the human behavior for blinds uses, which implies a high level of incertitude regarding the results [15]. Hourly step simulations are however well suited if the room is equipped with an automated management of sunscreens.

One way to display the results of climate-based daylight metrics is to use the “temporal map” representation, as proposed by Mardjalevic in [16].

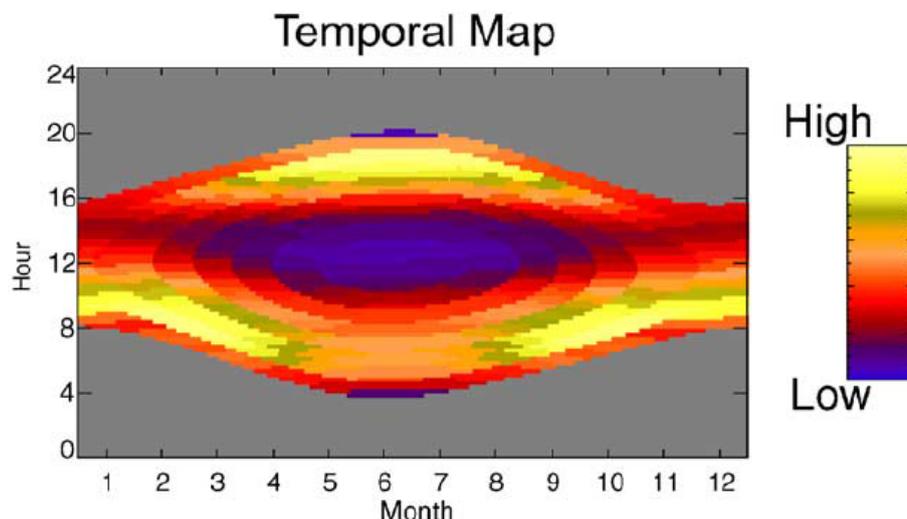


Figure 7: Example of temporal map. Source: J. Mardaljevic [16]

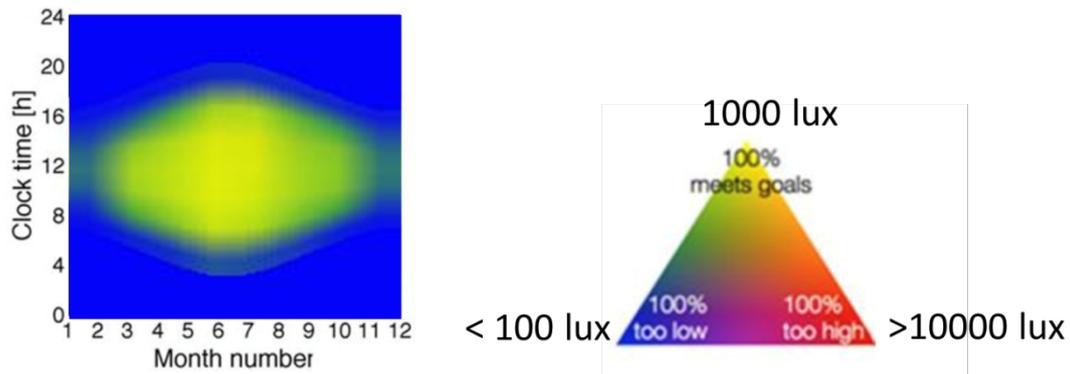


Figure 8: Goal based temporal map obtained with Lightsolve (yellow= Goal=1000 lux, blue= below goal, red=above goal)

References

- 11 Reinhart, C.F. and O. Walkenhorst, Validation of dynamic RADIANCE-based daylight simulations for a test office with external blinds. *Energy and Buildings*, 2001. 33(7): p. 683-697.
- 12 Reinhart, C. Effects of interior design on the daylight availability in open plan offices. in *ACEEE Summer Study on Energy Efficient Buildings*. 2002. Pacific Grove.
- 13 Reinhart, C.F. and M. Andersen, Development and validation of a Radiance model for a translucent panel. *Energy and Buildings*, 2006. 38(7): p. 890-904.
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- 15 Paule, B., Boutillier, J., Pantet, S., Shading device control Effective impact on daylight contribution. *Proceedings of the CISBAT'15 Conference*, Sept. 2015, Lausanne, Switzerland.
- 16 Mardaljevic, J. Spatial-temporal dynamics of solar shading for a parametrically defined roof system. *Energy and Buildings*, 2004. 36(8):p. 815-823.
- 17 Bodart, M., A. Deneyer, and V. Gilbert, Validation of the Belgian single-patch sky and sun simulator. *Building and Environment*, 2008. 43(11): p. 1892-1901.

Tools calculating this metric

The daylight autonomy is computed by different software whose DAYSIM or 3DSMaxDesign or DIVA. It can also be measured in scale models [17].

2.1.6. Useful Daylight Illuminance

Sources:

- Ch. Basurto
LESO-PB / EPFL Lausanne, Switzerland.
- M. Bodart / Université catholique de Louvain (UCL) (LOCI), Belgium.

Short description

To overcome the limits of the Daylight Factor notion, which does not take into account building orientation, location, and climatic data, Mardaljevic in 2004 [18] proposed to define a new metric, the useful daylight illuminance (UDI), based on a climate-based daylight modeling (CBDMM).

“Climate-based daylight modeling – CBDMM - is the prediction of various quantities as illuminances using real sky conditions from standard meteorological datasets” [19].

Instead of fixing a single target illuminance, the UDI measures the frequency, over a year, of the illuminance levels reaching a target range.

UDI is the annual occurrence of daylight illuminances across the workplane within a range.

This range was defined to encompass “useful illuminances for occupants” from a comprehensive review of occupant’s behavior with artificial lighting, dimming and blinds. Unlike, for artificial lighting the target is of 500 lx, some studies showed that daylight around 100 lx can be sufficient [20] and illuminances higher than 2000 to 2500 lx lead to a visual discomfort. To summarize, four categories were defined:

- Daylight illuminances less than 100 lx are not sufficient
- Daylight illuminances between 100-500 lx are generally sufficient and can be reinforced by artificial lighting
- Daylight illuminances between 500-2000/2500 lx are autonomous towards artificial lighting
- Daylight illuminances higher than 2000/2500 lx lead to visual discomfort

Limits defined above can be discussed depending the local activities and occupants.

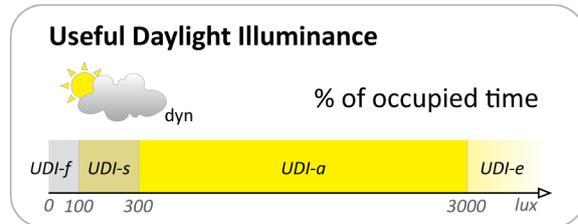
Anyway, the scheme is more important than the exact value and the useful UDI is considered as the collection of illuminances between 100 and 2000/2500 lx.

Related Metrics

As explained above, there are several ranges to classify satisfaction of illuminance level: not sufficient, useful and too high. Moreover in the useful UDI range, there are two complementary UDI ranges: supplementary and autonomous.

All ranges are defined as follows:

- UDI-f: UDI fell-short: The illuminance is less than 100 lx,
- UDI-s: UDI supplementary: The illuminance is greater than 100 lx and less than 300/500 lx,
- UDI-a: UDI autonomous: The illuminance is greater than 300/500 lx and less than 2000/2500 lx,
- UDI-e: UDI exceeded: The illuminance is greater than 2000/2500 lx,



with $UDI-s + UDI-a = \text{useful UDI}$.

We saw that limit ranges can vary depending on local activities and occupants.

One other consideration is which hours of the year have to be taken into account. This number can be defined by the occupied hours of the building or by daylight hours during the year.

Example

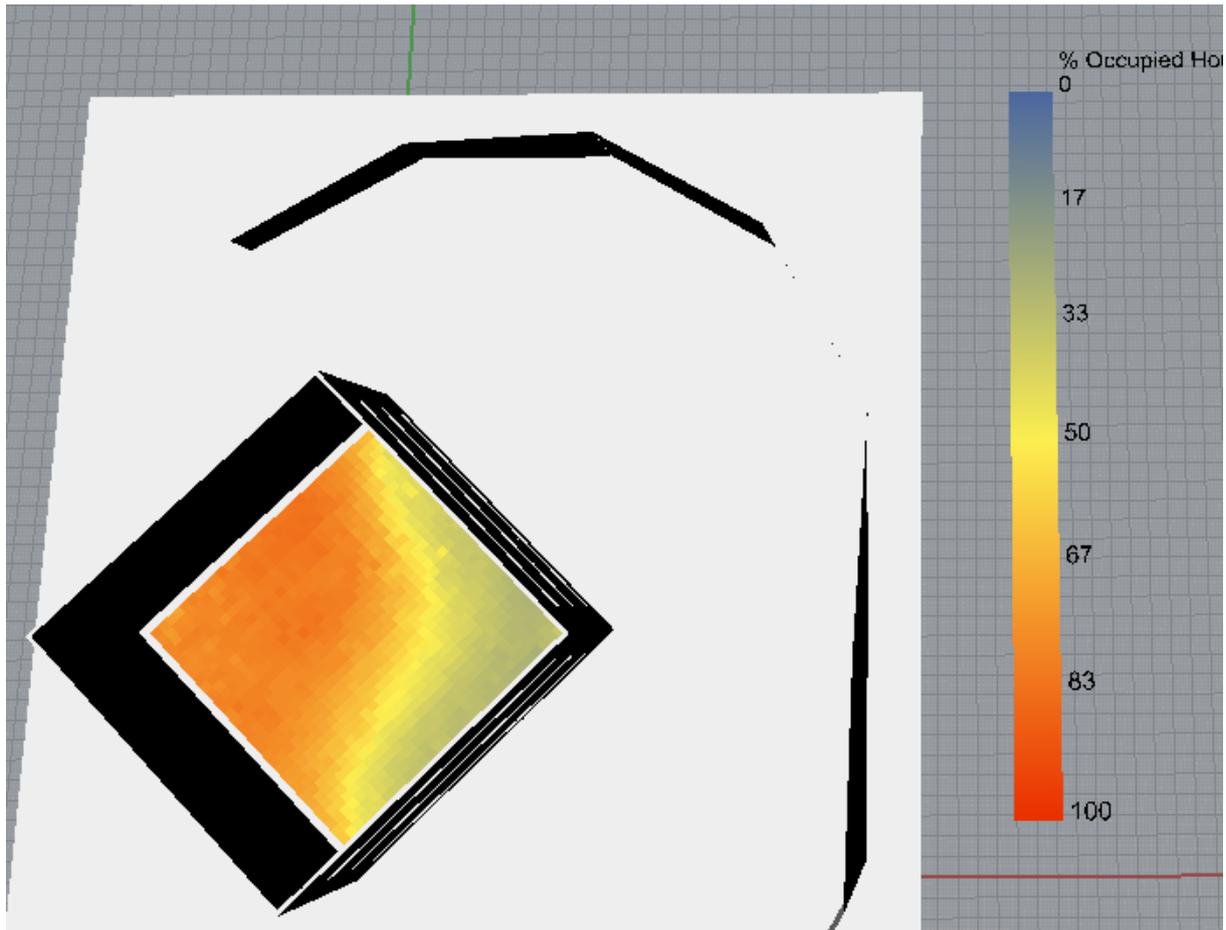


Figure 9: Example of useful daylight illuminance calculated with DIVA for Rhino

Example of calculation method

The three phase method was developed to enable the modelling of CFS for annual simulations using Radiance [23]. It relies on the use of bidirectional scattering distribution function (BSDF) as input data to compute yearly time-step calculations using climatic data files [24]. The three phase method is based on the daylight coefficient method proposed by Tregenza [25] and on the method to perform annual simulations using CFS proposed by Klems [26]. In the former method, the calculation of interior illuminances is performed considering two independent factors: the luminance of the sky and the form and materials of the surrounding surfaces. The method divides the sky in 145 sky divisions to later relate them to illuminance calculations in the interior of a virtual model.

The calculation is performed taking into account the daylight contribution for each of the 145 Tregenza sky subdivisions, in order to determine the contribution of each window in the

interior space (Figure 10 and 11). The five-phase method is an extension of the three-phase method, in the former the direct solar component is separated from the sky and interreflected calculation to achieve a better accuracy of the distribution of direct solar light in a room for complex glazing systems [27].

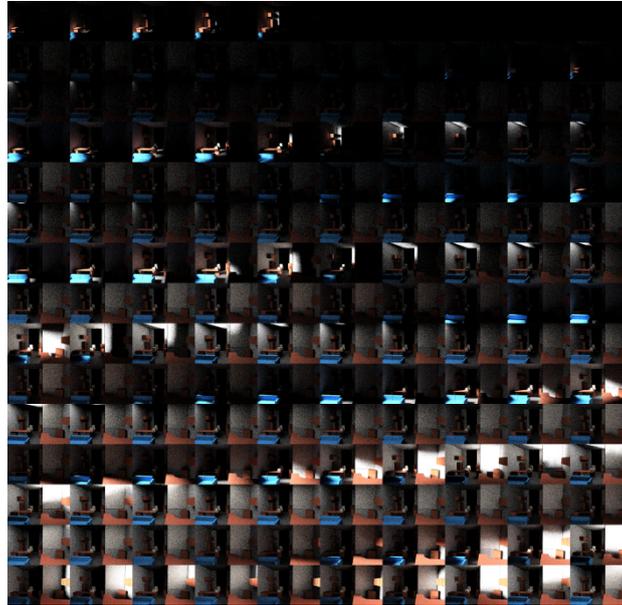


Figure 10: Image rendering of an office room showing the contribution of each of the 145 Tregenza sky subdivisions



Figure 11: Image renderings of an office room showing the daylight contribution of the south window (left), east window (center) and the combination of the two pictures (right)

Goal values

There is no official defined target as “if useful UDI is more than 80% your building is well daylight”. Indeed, targets depends to much of climate, orientation, application (computer work, paper work, drawing ,etc.), and more experimental applications are needed to fix target values.

Nevertheless, UDI is a useful metric to flag under and over lit zone (where the shading device would be needed) and to compare different configuration in a building [21].

For example, Piderit [22] defined in her thesis the following target for school in Chili.

She defined daylight space as:

- Irregular if useful UDI < 50%
- Regular if useful UDI [50% - 75%]
- Optimal if useful UDI > 75%

We can conclude that, when an office building is designed, more the useful range (between 100 and 2000 lx) will be achieved, more the illuminance level throughout the year will be comfortable for the occupants. Then, the objectives could be to maximize this value.

Limits

As far as UDI relies on hourly simulations, the method uses only one BSDF data file, which may correspond to a fixed position of the shading device. In real life, the position of the shading device should rely on some algorithm to be described for each calculation step. Moreover, this implies that BSDF data should be available for all the positions of the shading devices and all the positions of the shading devices should be known for the whole year (stochastic of the user behavior).

References

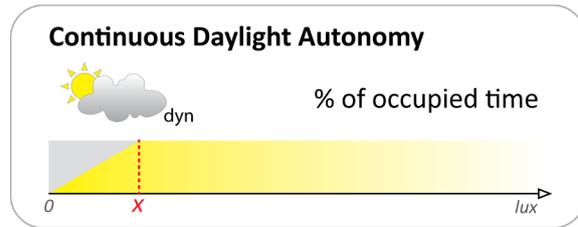
- 18 Nabil, A. and J. Mardaljevic, Useful daylight illuminance: a new paradigm for assessing daylight in buildings. *Lighting Research & Technology*, 2005. 37(1): p. 41-59.
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- 27 McNeil, A. *The Five-Phase Method for Simulating Complex Fenestration with Radiance*. Berkeley, CA Lawrence Berkeley National Laboratory.

Tools calculating this metric

The UDI can be computed with DAYSIM or DIVA. Radiance or 3DSMAXDesign allow computing illuminance levels for the all year. Then, users have to classify this data, to obtain the different UDI ranges.

2.1.7. Continuous Daylight Autonomy

Source: M. Bodart / Université catholique de Louvain (UCL)
Faculté d'architecture, d'ingénierie architecturale, d'urbanisme
(LOCI), Belgium



Short description

Defined by Rogers in 2006 [28]: the continuous daylight autonomy is a metric derived from the dynamic daylight autonomy. It is calculated by given a partial credit, which is granted when the illuminance is under the minimum level required. This metric highlights the benefic contribution of natural light even at low level. It models then the autonomy that would be met in a room equipped by a dimmable electric lighting system.

Examples

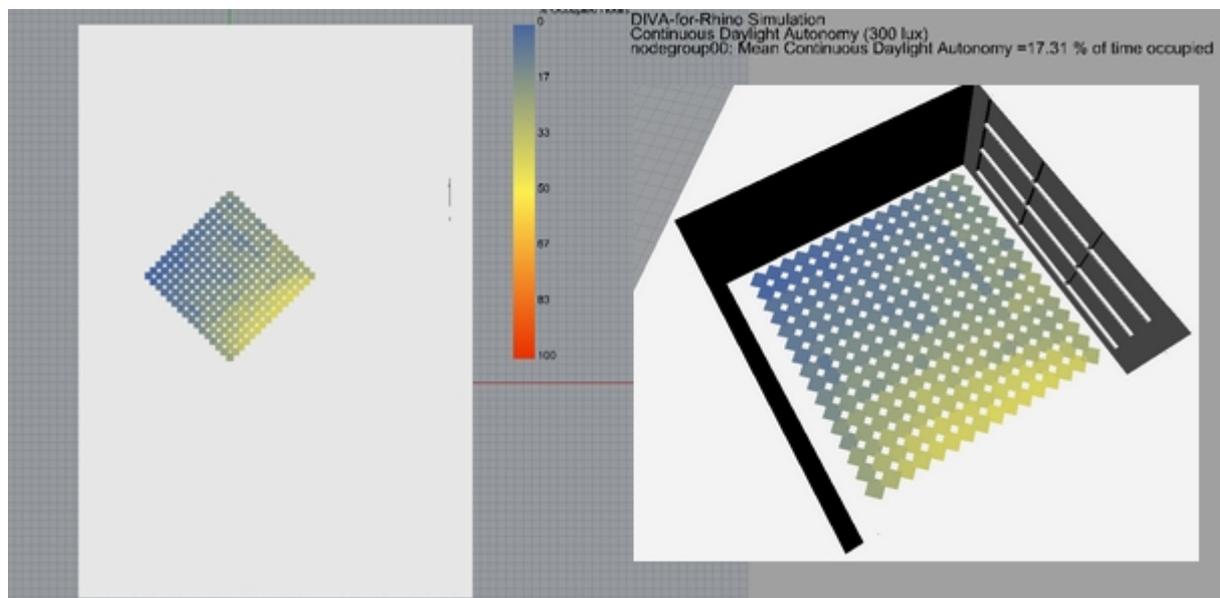


Figure 12: Example of Continuous Daylight Autonomy (for 300 lux) in a classroom, calculated by DIVA for Rhino

Limits

As for the Dynamic Daylight Autonomy, there are at the moment no target values. These target values are climate, occupancy and building type dependent and should probably be defined for each country. However, comparing the Continuous Daylight Autonomy can help the designers to choose among different design configurations.

References

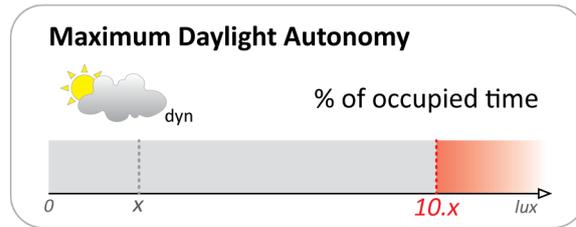
- 28 Rogers, Z., Daylighting metric development using daylight autonomy calculations in the sensor placement optimization tool. 2006, Architectural Energy Corporation: Boulder, Colorado, USA.

Tools calculating this metric

DIVA for Rhino, DAYSIM

2.1.8. Maximum Daylight Autonomy

Source: M. Bodart / Université catholique de Louvain (UCL)
Faculté d'architecture, d'ingénierie architecturale, d'urbanisme
(LOCI), Belgium



Short description

The maximum daylight autonomy is defined as the percentage of occupied hours during which the direct sun enters the buildings or excessive daylight levels are achieved. The maximum level is fixed with respect to the objective set for the daylight autonomy. It is 10 times this value (e.g. if the level objective of the DA is 300 lx, the maximum level will be 3000lx). This manner to fix the maximum value is the weakness of this metrics because it is intuitive instead of being based on experimental research.

Besides the illuminance threshold there is also a proposal for allowing a certain overstepping of the threshold: maxDA must not exceed 1% for more than 5% of a critical working plane area.

Goal values

Rogers proposes to fulfill the following criteria:

No more than 5% of the space can have a Maximum Daylight Autonomy higher than 1% [14] & [29].

Examples

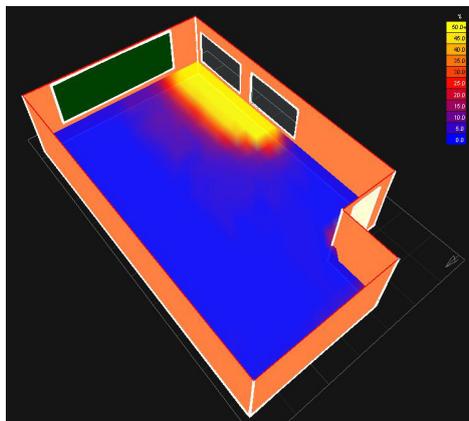


Figure 13: Example of results obtained with Daysim (imported in ECOTECT for visualization)

Limits

It is commonly agreed by experts that visual discomfort is linked with high luminance values and excessive contrasts, and not always correlated with illuminance values on the work plane. However, using DAm_{ax} in order to evaluate critical situations, when too much daylight enter the building, gives a first idea of location in the room where such glare problems could occur.

References

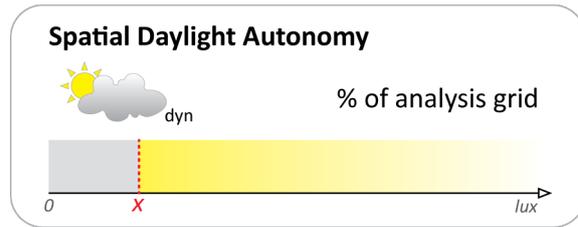
- 29 Daylighting Metric Development Using Daylight Autonomy Calculations In the Sensor Placement Optimization Tool (Development Report and Case Studies), CHPS Daylighting Committee, 2006

Tools calculating this metric

DAYSIM

2.1.9. Spatial Daylight Autonomy

Source: D. Geisler-Moroder / Bartenbach GmbH, Austria



Short description

To assess the quality of daylit spaces the Illuminating Engineering Society IES defines the spatial daylight autonomy sDA [30]. This metric describes the annual sufficiency of ambient daylight levels in interior rooms. The sDA is defined as percentage of the task area that meets a minimum daylight illuminance level for a given fraction of operating hours per year, i.e., that meets a defined daylight autonomy level [31]. The recommended thresholds are 300 lux and 50% of operating hours, daily from 8am to 6pm local time incorporating daylight savings time, and the sDA value is given in percent. Thus, the spatial daylight autonomy is calculated as

$$sDA_{300,50\%} = \frac{\text{Analysis area with } E \geq 300\text{lx for at least 50\% of the operating hours}}{\text{Overall analysis area}} * 100$$

According to IES LM-83-12 [30] target values for the spatial daylight autonomy are:

- sDA_{300,50%} ≥ 55%: nominally acceptable daylight sufficiency
- sDA_{300,50%} ≥ 75%: preferred daylight sufficiency

In the calculation sun shading or glare protection systems – if any – are activated if more than 2% of the analysis area receives direct sunlight with at least 1000 lux. Thus, the calculation engine used has to provide the possibility to define a control strategy and to change the façade states in the course of the annual simulation. Alternatively, all possible façade states can be calculated separately and the annual results combined corresponding to the sun shading control in a post-processing step.

RADIANCE [32] allows scripting of own control strategies and thus the evaluation of dynamic shadings. Using the 3-phase method annual calculations including façade systems represented by their BSDF data can efficiently be performed. For the calculation of the sDA the annual illuminances at each measurement point are simulated and the daylight autonomy [31] for a threshold level of 300 lux is derived. The fraction of the analysis area, i.e. the percentage of measurement points, exceeding a daylight autonomy of 50% gives the sDA_{300,50%}. Prepared scripts to calculate the sDA with RADIANCE are publicly available [33].

Example

For a given office space the spatial daylight autonomy is evaluated for various façade configurations.

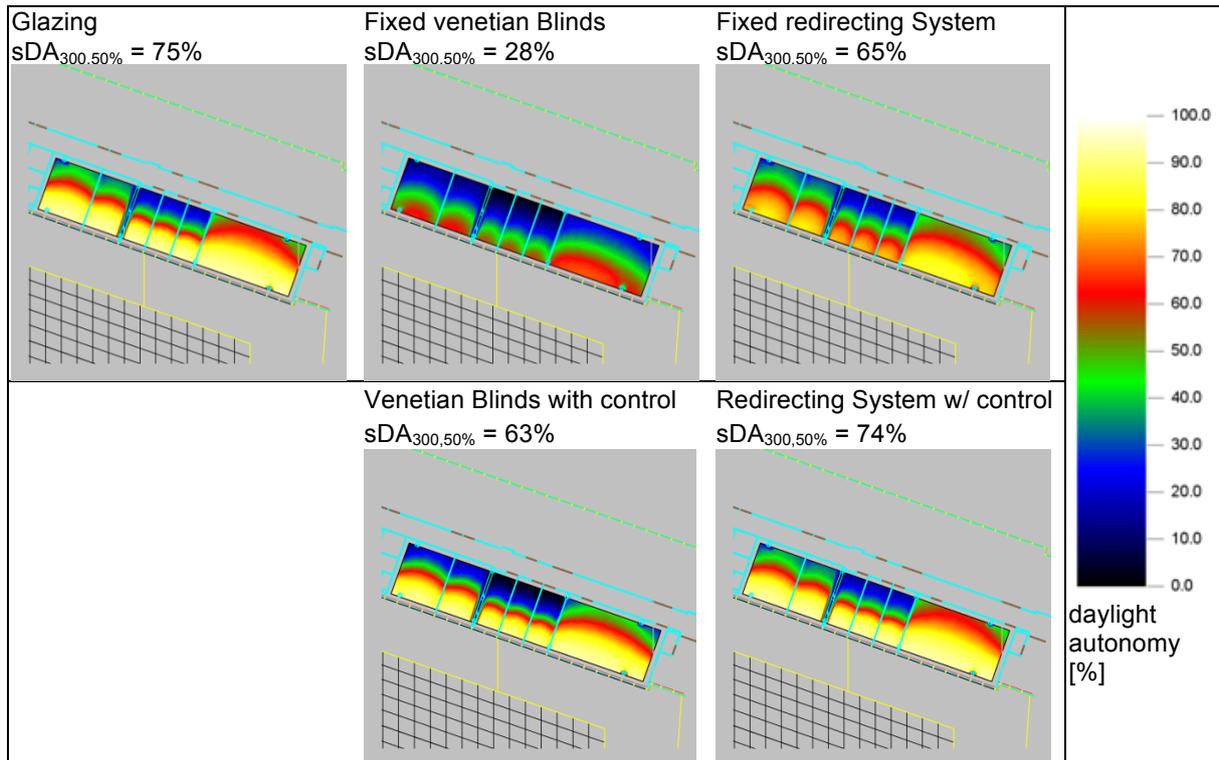


Figure 14: Example of daylight autonomy distributions in office spaces with various façade configurations. The fraction of the analysis area with more than 50% daylight autonomy gives the spatial daylight autonomy sDA (RADIANCE simulation)

Limits

The spatial daylight autonomy relies on hourly calculations based on climate data, thus it takes sky and sun contributions into account and accounts for dynamic shading systems. However, this leads to high complexity in the calculation and – though there are scripts available [33] – there is still deep knowledge and simulation effort required from the user. The sDA does not provide information about possible visual discomfort. Thus, the annual sunlight exposure should always be additionally calculated.

References

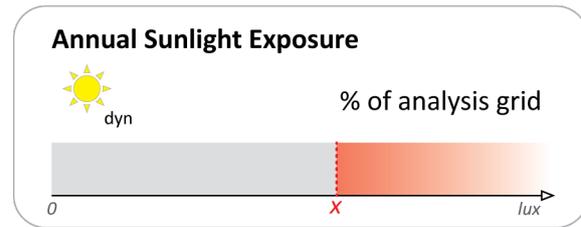
- 30 IES, Illuminating Engineering Society, (2012). IES LM-83-12, Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE).
- 31 Reinhart, C., Walkenhorst, O., (2001). Validation of dynamic RADIANCE-based daylight simulations for a test office with external blinds. *Energy and Buildings*, 33(7), S. 683-697.
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- 33 Djunaedy, E., Mahic, A., Van Den Wymelenberg, K., (2013). *Spatial Daylight Autonomy & Annual Sunlight Exposure, The LM-83 Radiance Script (using 3-phase method)*. Online: <http://www.idlboise.com/design-tool/lm-83-automation>. 12th International Radiance Workshop, Golden, Colorado.

Tools calculating this metric

RADIANCE (scripts available),
DIVA for Rhino, Daysim

2.1.10. Annual Sunlight Exposure

Source: D. Geisler-Moroder / Bartenbach GmbH, Austria



Short description

As a criterion for potential visual discomfort in interior work environments the Illuminating Engineering Society IES specifies the annual sunlight exposure ASE [34]. It is defined as percentage of the task area that exceeds a specified direct sunlight illuminance level at more than a specified number of operating hours per year. The recommended thresholds are 1000lx and 250 hours per year. Again daily operating hours from 8am to 6pm local time incorporating daylight savings time are used and the ASE value is given in percent. Thus, the annual sunlight exposure is calculated as

$$ASE_{1000,250h} = \frac{\text{Analysis area with direct sunlight } (\geq 1000\text{lx}) \text{ for at least 250 hours per year}}{\text{Overall analysis area}} * 100$$

No definite target values for the annual sunlight exposure are given in [34]. However, the discussion of supporting research proposes the following classification:

- $ASE_{1000,250h} \geq 10\%$: unsatisfactory visual comfort
- $ASE_{1000,250h} < 7\%$: neutral, nominally acceptable spaces
- $ASE_{1000,250h} < 3\%$: clearly acceptable spaces

In the calculation of the annual sunlight exposure static sun shading or glare protection systems – if any – shall be included, whereas moveable devices shall be excluded from the simulation.

For the calculation of the annual sunlight exposure software tools are needed that allow annual daylight simulations with direct sunlight only. For example RADIANCE [35] is able to perform these kind of simulations. Scripts to calculate the ASE with RADIANCE are publicly available [36].

Example

For a given office space the annual sunlight exposure is evaluated for various façade configurations.

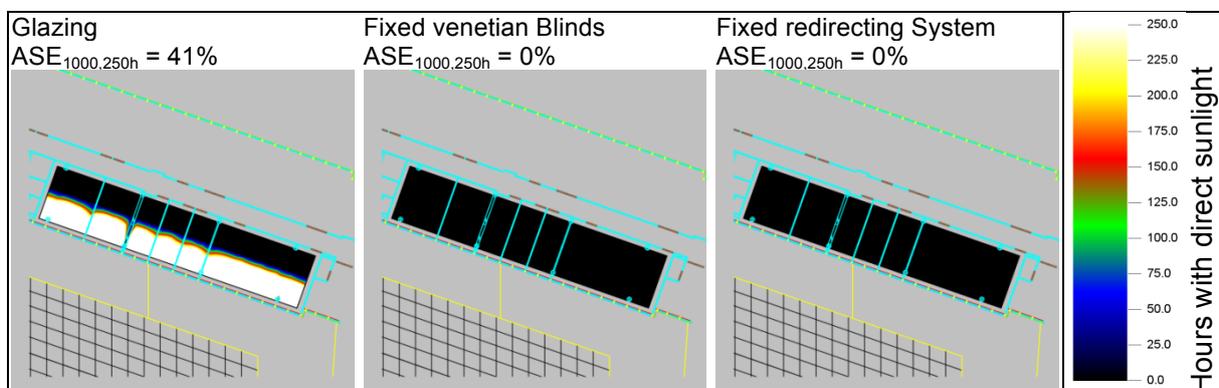


Figure 15 : Example of sunlit hours in office spaces with various façade configurations. The fraction of the analysis area with more than 250 hours of direct sunlight gives the annual sunlight exposure ASE (RADIANCE simulation)

Limits

Similar to the spatial daylight autonomy the annual sunlight exposure relies on hourly calculations based on climate data. This leads to high complexity in the calculation and deep knowledge and simulation effort is required from the user. Additionally, a software tool is needed that is able to perform annual daylight calculations for direct sunlight only.

References

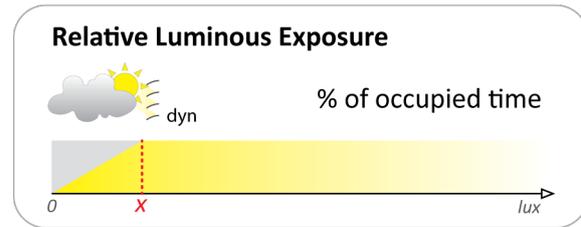
- 34 IES, Illuminating Engineering Society, (2012). IES LM-83-12, Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE).
- 35 Ward, G., Shakespeare, R., (1998). Rendering with Radiance. Morgan Kaufmann Publishers.
- 36 Djunaedy, E., Mahic, A., Van Den Wymelenberg, K., (2013). Spatial Daylight Autonomy & Annual Sunlight Exposure, The LM-83 Radiance Script (using 3-phase method). Online: <http://www.idlboise.com/design-tool/lm-83-automation>. 12th International Radiance Workshop, Golden, Colorado.

Tools calculating this metric

RADIANCE (scripts available)
DIVA for Rhino

2.1.11. Relative Luminous Exposure

Source: Jan de Boer, FhG IBP, Stuttgart



Short description

To assess the impact of daylight on indoor lighting conditions and the resulting energy need for supplementary lighting, the (relative) usable luminous exposure is used as a time-integral assessment parameter. A schematic representation of this parameter is given in Figure 16. In a given daylight-responsive, dimming lighting control scheme, the relative usable luminous exposure $H_{N,rel}$ specifies the share of daylight (as a percentage of the required quantity of light E_m) that is available in a defined area / at a defined control point during the respective time interval:

$$H_{N,rel} = \frac{1}{E_m t_A} H_N \cdot 100 [\%]$$

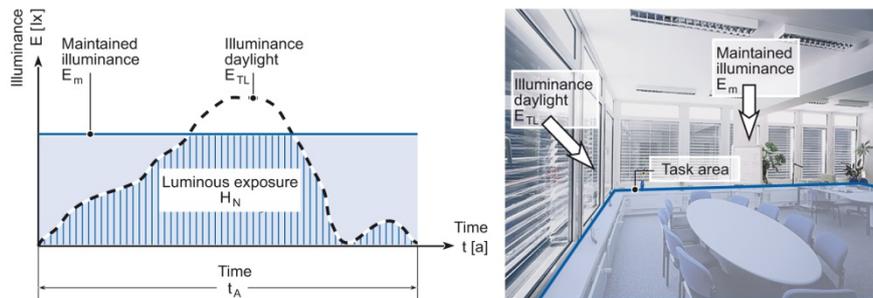


Figure 16: Schematic representation of the usable luminous exposure using a typical daytime illuminance profile



Figure 17: Photographs of the façade operating modes considered in a façade status-related, relative usable luminous exposure

Generally, the lighting properties of façades change depending on activation of the solar radiation and/or glare protection systems, as depicted in Figure 17. Consequently, an extended façade-related definition of the relative usable luminous exposure should be used, depending on the operating times $t_{rel,SNA}$ and $t_{rel,SA}$ with deactivated and activated solar protection devices:

$$H_{N,rel} = t_{rel,SNA} \cdot H_{N,SNA,rel} + t_{rel,SA} \cdot H_{N,SA,rel}$$

where $H_{N,SNA,rel}$ and $H_{N,SA,rel}$ are the particular relative luminous exposures for the times with sunshading not activated (SNA) and respectively sunshading activated (SA).

The extended definition of the relative usable luminous exposure respectively allows performing a differentiated analysis of indoor space lighting as a function of the construction and the operating mode of the complex fenestration system. It is possible to describe the impact the different operating states have on the total usable luminous exposure. Therefore, any status involving solar shading and/or glare protection (or not) may be evaluated and individually optimized, if needed.

The quantities can be calculated on an hourly basis with lighting simulation software or can be determined with simple regression based approaches (which themselves are based on detailed simulations) [37] as implemented in several standards (EN 15193-1 [38][40] ISO 10916 [39]) on a monthly or an annual basis, for different latitudes and climates. Key construction parameters are accounted for, such as outside obstructions, façade parameters - for vertical facades and rooflights – as well as major room parameters.

Example

The example depicted in Figure 18 and Figure 19 illustrates for a typical office situation the implementation of the approach into methods for determining lighting energy demand.

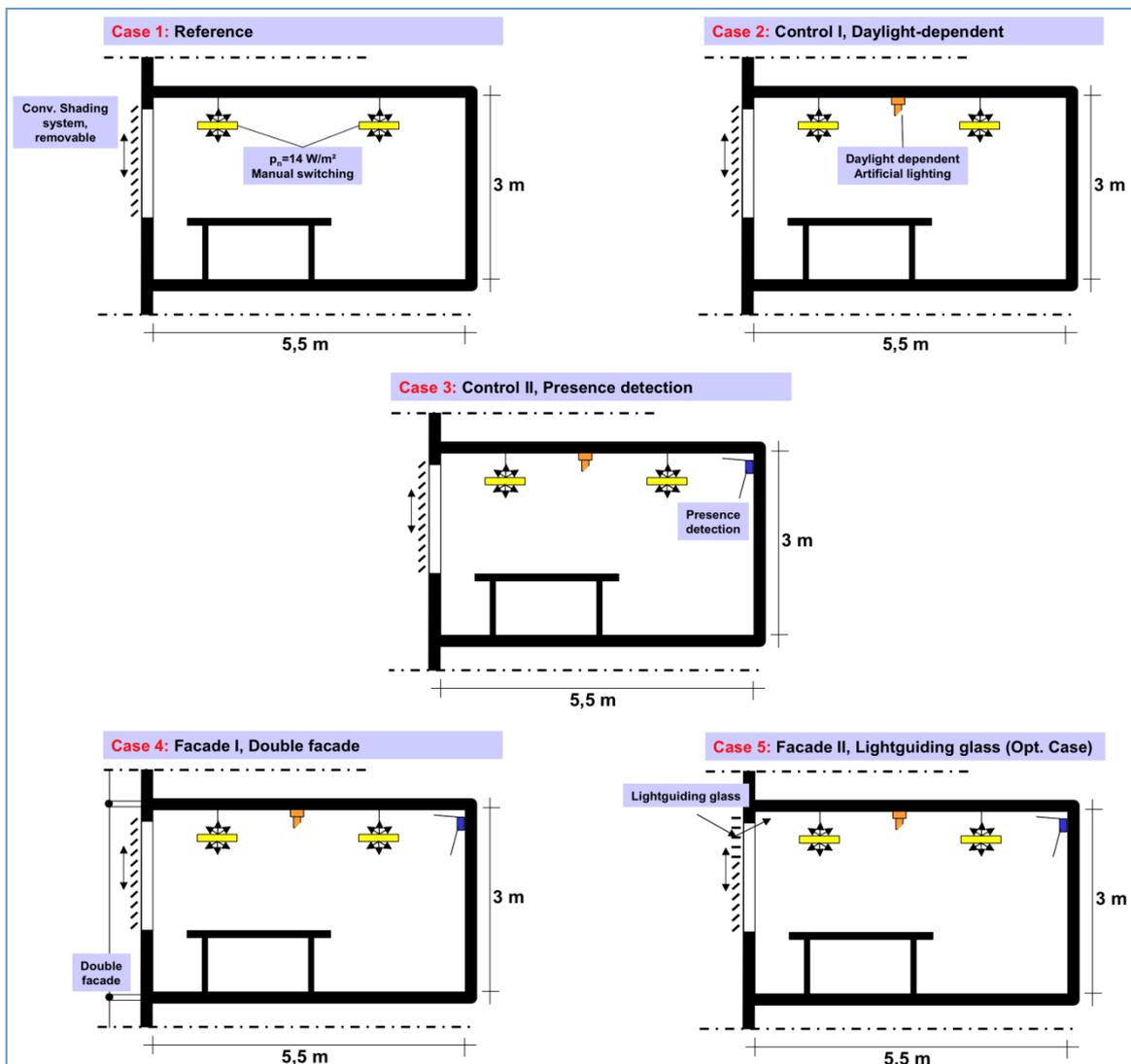


Figure 18: Example cases to illustrate the impact of different façades and lighting control solutions on the lighting energy demand

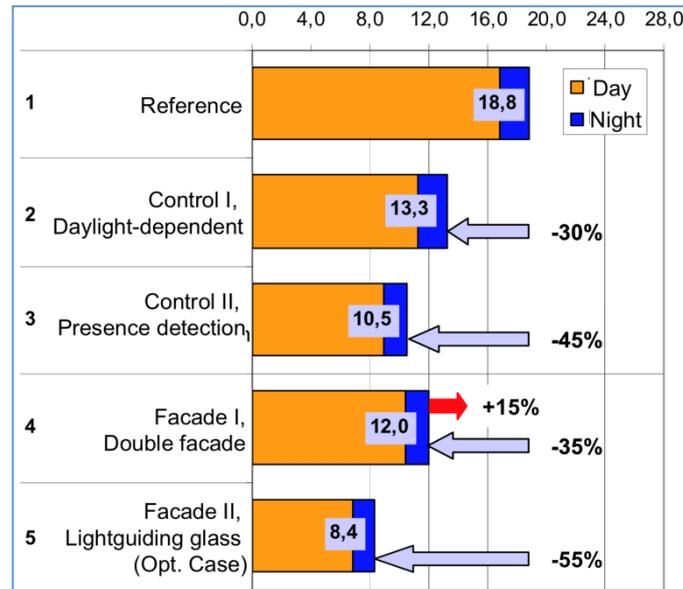


Figure 19: **Impact of different façades and lighting control solutions as in Figure 18** on the lighting energy demand ($\text{kWh/m}^2\cdot\text{a}$). The calculations employ the approach of the “relative luminous exposure”

Limits

Similar to other methods the detailed (exact) determination of the relative luminous exposure relies on hourly calculations with rather complex simulation tools based on climatic data. The available simplified approaches allow for many practically relevant cases a fast determination. Nevertheless the simplified approach is restricted to standard geometries (shoebox type spaces laterally lit or lit by rooflights).

References

- 37 de Boer, J.; Mergenthaler, K.: A simple general method to rate daylight supply of indoor spaces with vertical façades, Report of Fraunhofer Institut for Building Physics WB 154/2011e. Stuttgart (2011).
- 38 EN 15193-1: Energy performance of buildings-Energy requirements for lighting – Part 1: Lighting energy estimation. CEN, Brussels (2005)
- 39 ISO 10916 “Calculation of the impact of daylight utilization on the net and final energy demand for lighting”, ISO, Geneva (2014)
- 40 prEN 15193-1:2014, Energy performance of buildings — Energy requirements for lighting — Part 1: Specifications, CEN Draft, Brussels (2015)

Tools calculating this metric

Hourly calculations:

- Adapted RADIANCE Version

Simplified approaches:

- Energy consulting tools implementing the European Standard EN 15193 or the ISO Standard ISO 10916
- <http://www2.ibp.fhg.de/wt/fassadenauslegung/>, only German climate.

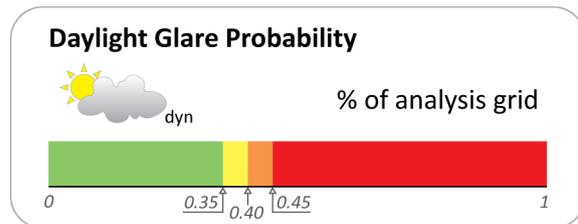
IEA Task 50 Lighting Retrofit Adviser: Component “CFS-Express” and “On-site Optimizer”

2.2. Daylight glare metrics

Source: Jan Wienold, EPFL LIPID, Lausanne Switzerland

Two metrics to describe glare from daylight are commonly used and also included in design tools. These are the Daylight Glare Index (DGI) and the Daylight Glare Probability DGP. The DGI describes the glare sensation on a scale (Hopkinson, 1972), whereas the DGP describes the probability that a person is disturbed by daylight glare ([41] Wienold and Christoffersen, 2006). The latter metric was developed under daylight conditions and has shown in several experiments to provide better agreements with users' perception towards daylight glare than the DGI.

2.2.1. Daylight Glare Probability (DGP)



Short description

The daylight glare probability (DGP) is an approach to predict discomfort glare for offices like environments.

The daylight glare probability DGP is a glare index, which uses the vertical eye illuminance (to consider a saturation effect at the eye) and individual glare sources of high luminance (like the sun or specular reflections of the sun) to estimate the fraction of dissatisfied persons. Climate based simulations or simplified calculation procedures of the DGP enable to estimate the frequency of occurrence of glare situations. This enables to evaluate the full year behaviour of the visual environment. The DGP equation is an empirical formula connecting directly measurable physical quantities (e.g. source luminance, vertical eye illuminance, solid angle of the glare source, background luminance, etc.) with the glare experienced by subjects. The important variables are:

- The vertical illuminance at eye level: This value plays the main role in experiencing glare at daylight-orientated workplaces. In addition, this value is also used as adaptation level within the term of the individual glare sources.
- The luminance of the glare source. In the case of windows: the luminance of the sky as seen through the window (the brighter the source or sky, the higher the index);
- The solid angle subtended by the source. In the case windows: the apparent size of the visible area of sky at the observer's eyes (the larger the area, the higher the index);
- The angular displacement of the source from the observer's line of sight. In the case of windows: the position of the visible sky within the field of view (the further from the centre of vision, the lower the index);

$$DGP = 5.87 \cdot 10^{-5} \cdot E_v + 9.18 \cdot 10^{-2} \cdot \log\left(1 + \sum_i \frac{L_{s,i}^2 \cdot \omega_{s,i}}{E_v^{1.87} \cdot P_i^2}\right) + 0.16$$

Ev: vertical eye illuminance [lux] P: position index [-]
 Ls: luminance of source [cd/m²] ωs: solid angle of source [-]
 i: glare source number

Example

The DGP can be applied to any daylight oriented indoor space which is mainly side-lit and where the expected tasks are comparable to office tasks.

In cases of multiple possible positions of tasks or workplaces the expected worst-case position should be investigated. These positions are usually close to the façade and/or where you can expect view connection to a low sun position.

To avoid discomfort glare for office-like spaces, the Daylight Glare Probability DGP for the main viewing direction should not exceed a value of 0.45 for 5% of the occupied time. Table 2 shows the categorization of DGP values.

Glare criterion	Daylight Glare Probability
Glare is mostly not-perceived	$DGP \leq 0.35$
Glare is perceived but mostly not disturbing	$0.35 < DGP \leq 0.40$
Glare is perceived and often disturbing	$0.40 < DGP \leq 0.45$
Glare is perceived and mostly intolerable	$DGP > 0.45$

Table 2: Glare perception as a function of the DGP values

Another possibility is to use threshold values (DGPt) for different levels of glare protection, see Table 3.

	DGPt	Maximum allowed exceedance during reference usage time
Recommendation for minimum glare protection	0.45	5%
Recommendation for medium glare protection	0.40	5%
Recommendation for high glare protection	0.35	5%

Table 3: Proposed values of threshold DGPt for different levels of glare protection

See examples simulated with DIAL+ & Geronimo exposed at the end of this document (cf. Figure 37 & Figure 38).

Limits

The glare sensitivity is increasing with age. In addition to this, the variance of glare perception between different persons is large.

DGP should not be applied to situations, where it can be expected that the vertical illuminance is not a good indicator for the glare perception; such situations include: task position far away from the window, vending areas of shops, sport halls and deep or dark spaces with very small windows.

References

- 41 Wienold J, Christoffersen J. Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras. *Energy Build* 2006;38:743–57

Tools calculating this metric

DIAL+Lighting

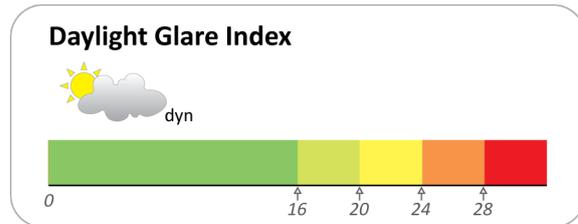
Geronimo

Radiance

DIVA

2.2.2. Daylight Glare Index (DGI)

Source: Jan Wienold, EPFL, LIPID, Lausanne, Switzerland



Short description

The Daylight Glare Index DGI (or Cornell glare equation) is a modified version of the British glare index BGI, to predict glare window [Chauvel et al., 1982; Hopkinson, 1972]. The equation is expressed as follows:

$$GI = 10 \log_{10} 0.48 \sum_{i=1}^n \frac{L_s^{1.6} \cdot \Omega_s^{0.8}}{L_b + 0.07 \omega_{wi}^{0.5} L_{wi}}$$

Where

L_s : luminance of the glare source(s) [cd/m^2]

L_b : background luminance [cd/m^2]

L_w : weighted average luminance of the window, in function of the relative areas of sky, obstruction and ground [cd/m^2]

ω : solid angle subtended by the window [sr]

Ω_s is the solid angle subtended by the glare source modified by the position of the source with respect to field of view and Guth's position index [sr].

Example

The DGI expresses the magnitude of glare and its values are defined as:

Glare criterion	Daylight Glare Index DGI
Just imperceptible	16
Just acceptable	20
Just uncomfortable	24
Just intolerable	28

Table 4: Glare perception as a function of the DGI values

See examples simulated with DIAL+ & Geronimo exposed at the end of this document (cf. Figure 37 & Figure 38).

Limits

The DGI was developed only under artificial conditions and the applicability for dispersed glare sources as well as for very large glare sources is unclear. It does not encounter for a saturation effect at the eye.

Reference

- 42 Bellia Laura, et al. (2008) *Daylight glare: a review of discomfort indexes*. In: Visual quality and energy efficiency in indoor lighting: today for tomorrow, 31 Mar 2008, Roma, Italia. (In Press)

Tools calculating this metric

DIAL+Lighting

Geronimo

Radiance

3. ENERGY MONITORING PROCEDURES FOR ELECTRIC LIGHTING SYSTEMS

3.1. Flash diagnosis sheet for quick analysis

Source: B. Paule / Estia SA Lausanne

A simplified diagnosis sheet for a quick analysis is presented in Figure 20. This method is used in Switzerland by Estia within the framework of quick building-stock analysis.

A more detailed method is presented in subtask D within the framework of case-studies analysis.

Lighting "FLASH" Diagnosis Date : / /

Building : Realised by :

Room: Orientation 

Floor:

Width: m Depth: m Height: m

FLOOR:
 Very Dark Dark Medium Light Very Light

WALLS:
 Very Dark Dark Medium Light Very Light

CEILING:
 Very Dark Dark Medium Light Very Light

Window Sill: cm Lintel height: cm

Glazings: Single glazing Double glazing Triple glazing
 Clear glass Tinted/Reflective glass

Frame Fraction: 10% 20% 30% 40% 50%
(relative to the window area)
 Notes:

Outdoors blinds:
 Manual Motorized Automated

Indoors blinds:
 Manual Motorized Automated

Schematic representation of the room (Luminaires, Lighting zones et Switch position (luminaires + blinds))

Horizontal Illuminance centre of the room (0.80) [All luminaires ON : lux
 All luminaires OFF : lux

Vertical Illuminance centre Blackboard [All luminaires ON : lux
 All luminaires OFF : lux

LUMINAIRES type 1

Type Luminaire: Ceiling Hanging Recessed Standing Wall

Direction: All Downwards Upwards Combined

Reflector: None White Aluminium

Down filters Diffuseur Grid None

Dispositif Haut: Diffuseur None

Ballast: Magnetic Electronic

Fluorescent Compact-Fluo Incandescent Halogen Metal Halide LEDs

16 mm 26 mm 38 mm

Nb lamps per luminaire: Lamp Power: W

LUMINAIRES type 2

Type Luminaire: Ceiling Hanging Recessed Standing Wall

Direction: All Downwards Upwards Combined

Reflector: None White Aluminium

Down filters Diffuseur Grid None

Dispositif Haut: Diffuseur None

Ballast: Magnetic Electronic

Fluorescent Compact-Fluo Incandescent Halogen Metal Halide LEDs

16 mm 26 mm 38 mm

Nb lamps per luminaire: Lamp Power: W

Figure 20: Example of the Estia flash lighting sheet for school buildings

The results of a study that was performed in Switzerland with this “Flash” analysis method are showed hereafter. It focused on twenty classes in 9 primary schools.

Diagnosis

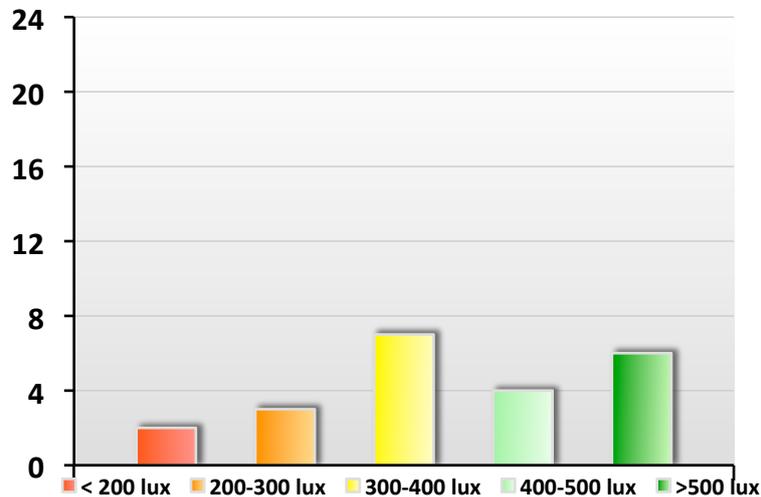


Figure 21: Illuminances on the work plane

Figure 21 shows the illuminance values measured on the work plane of each of the classrooms (centre of the room). It is found that in almost 20% of cases, the 300 lux value is not reached before refurbishment.

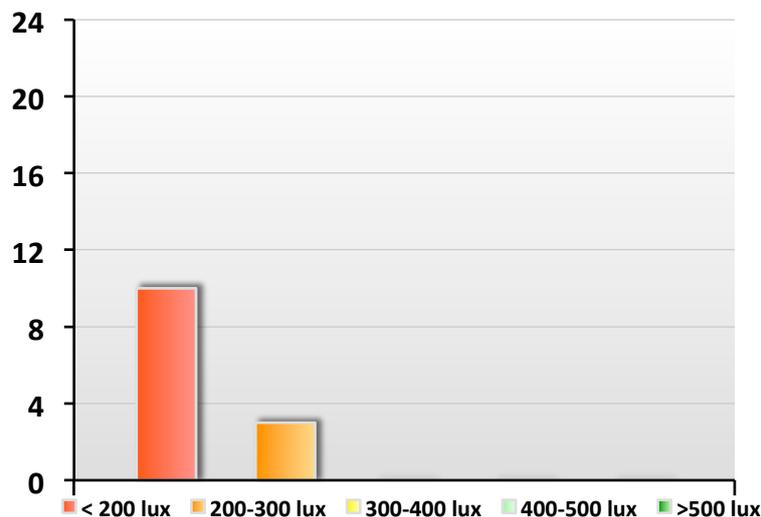


Figure 22: Illuminances on the blackboard

Figure 22 shows that in all cases, the illumination on the blackboard is less than 300 lux while it is expected to reach 500 lux. This is due to the fact that, before refurbishment, no specific luminaires were dedicated to the blackboard lighting. This is a strong incentive to refurbish the lighting installation.

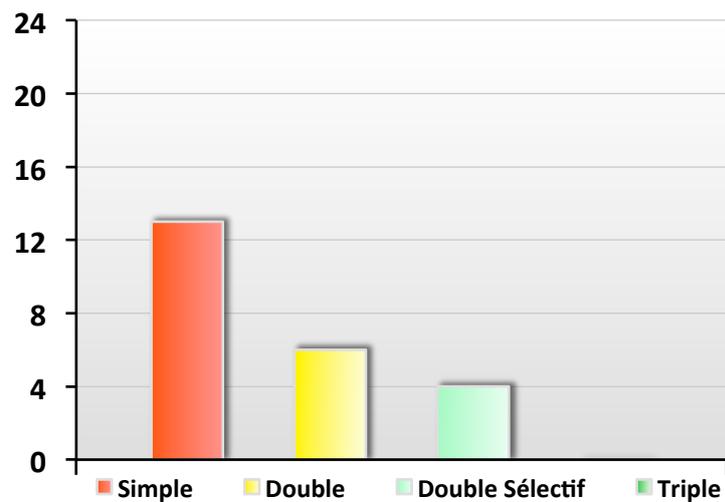


Figure 23: Types of glazing

Figure 23 shows that, in half of the cases, the windows have single glazing. Once again, this is a strong incentive to refurbish the lighting installation.

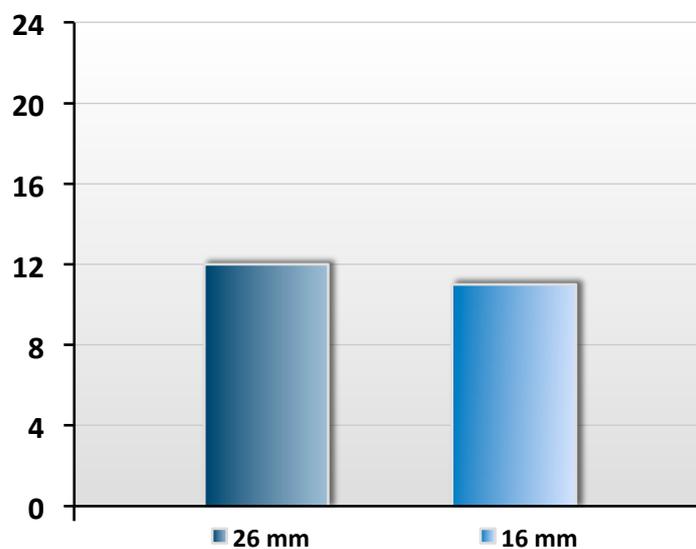


Figure 24: Types of light sources

Figure 24 shows that all the visited classrooms are equipped with fluorescent tubes which is correct from the energy point of view. However, half of them are fitted with 26 mm tubes, reflecting the age of the facilities.

Daylighting

Figure 25 shows a comparison between the existing situation and the refurbishment project. One should notice that the daylighting performance is reduced after refurbishment. This perfectly illustrates the risks of degradation of daylighting potential that are related to replacement of windows (reduced light transmission), the frame change (increase of the opaque fraction), or the implementation of an external insulation. Furthermore, in this particular case, the blinds casing has been integrated into the upper part of the opening, which reduces the glazed area.

Of course, it would have been possible to design a more efficient solution, but it was interesting to show here the potential of degradation that might be associated to refurbishment actions.

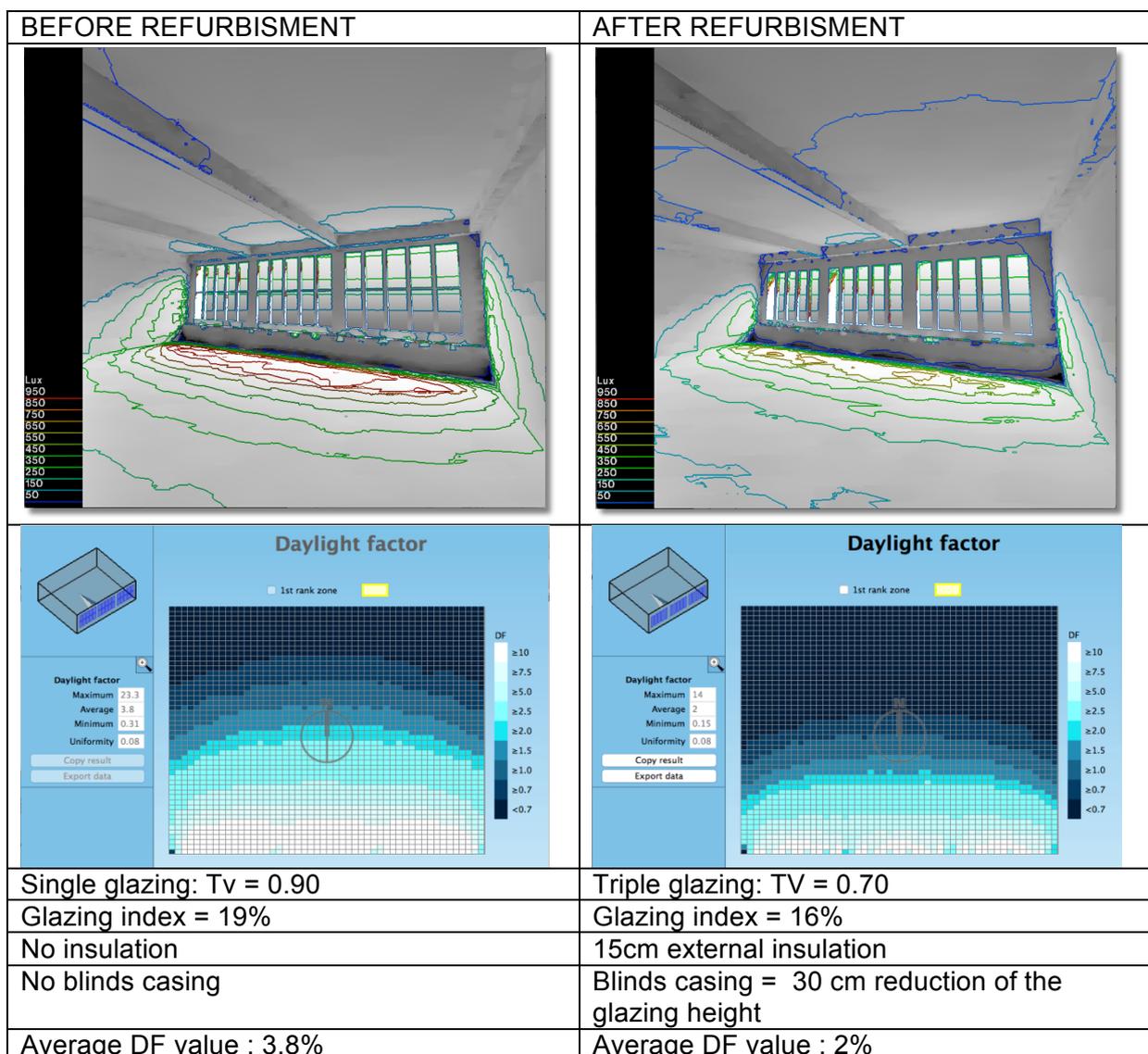


Figure 25: Comparison of the daylighting contribution Before and After the refurbishment

Electric lighting

BEFORE REFURBISHMENT	AFTER REFURBISHMENT
12 direct luminaires with grid	9 +2 direct luminaires with grid
Fluorescent tubes 2 x 36 W	Fluorescent tubes 2 x 31 W
Installed power: 12 W/m ²	Installed power : 9.6 W/m ²
Average Illuminance: 436 Lux	Average illuminance: 471 Lux
Command = Manual	Command: Auto-OFF, absence detector
Manual venetian blinds	<ul style="list-style-type: none"> Automated venetian blinds

Figure 26: Comparison of the illuminance distribution due to electric lighting Before and After the refurbishment

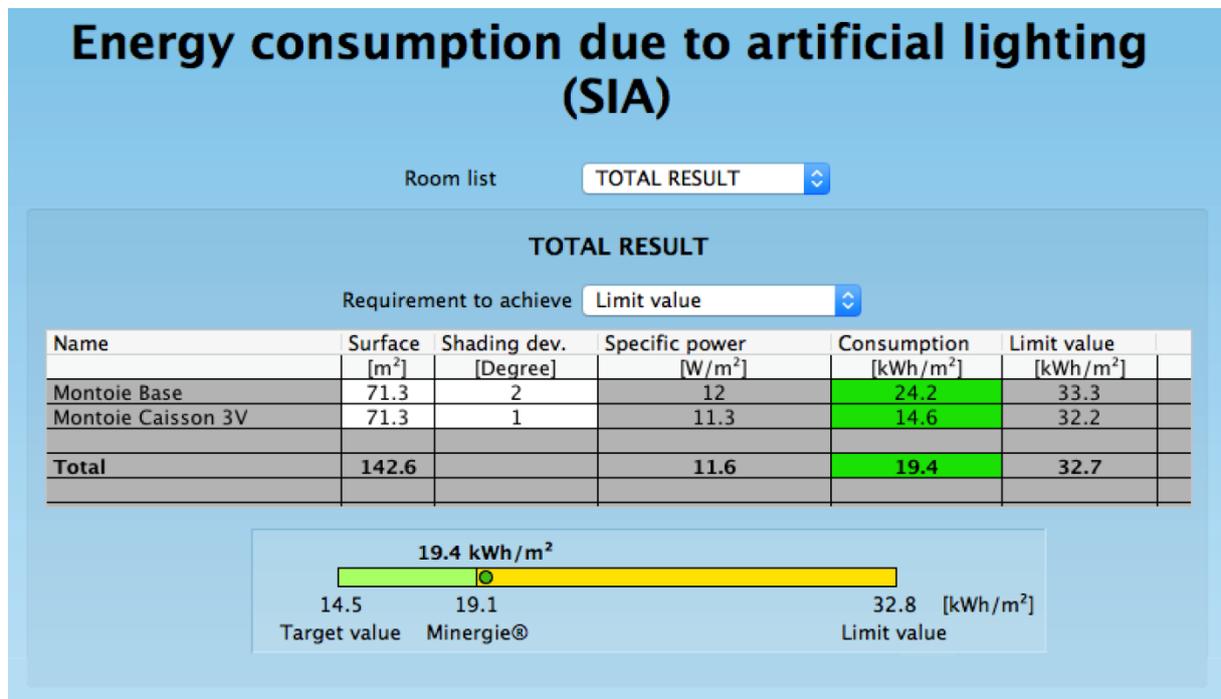


Figure 27: Comparison of the annual electricity consumption due to lighting, according to the Swiss Standard (SIA 380/4)

4. BENCHMARK ON CASE STUDIES

The experts have applied the metrics described in C4-1 to the case study described in the C2 document in order to give a concrete view of the different approaches.

In this section, we display the results obtained by the simulation tools, for the different metrics described before. The case study corresponds to the “*After Refurbishment*” situation described in C2 document (*cf. C2.6.1 Description of the case study for lighting simulations*)

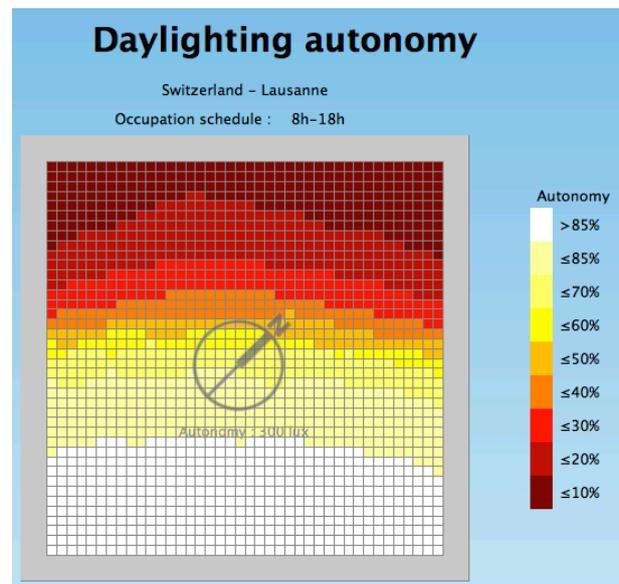
4.1.1. Diffuse Daylight Autonomy (DDA)

DIAL+Lighting

Source: B. Paule / Estia

- Target illuminance Level: 300 lux
- Occupation time: 8am - 6pm
 - Max: 96%,
 - Mean: 53.5%,
 - Min: 3%

Figure 28: Diffuse Daylight Autonomy for the initial case-study



4.1.2. Dynamic Daylight Autonomy (DA)

Daysim

Source: M. Bodart

- Target illuminance Level: 300 lux
- Occupation time: 8am - 5pm,
- Holidays From July to August,
- Weekend: Saturday and Sunday
- Sensor: Centre of the room

Mean value: 77 %

Electric lighting management system	Annual electric lighting energy use [W/m ²]
Manual on/off near the door	7
Switch off occupancy (delay 5 minutes)	6.8
Switch on/off occupancy control (delay 5 minutes)	13.2
Photo sensor controlled dimming	3
Combination switch off occ & dimming	2.6
Combination on/off occupancy and dimming	4

Table 5: Results for the refurbished case-study (Daysim)

IES-VE

Source: M. Jörgensen

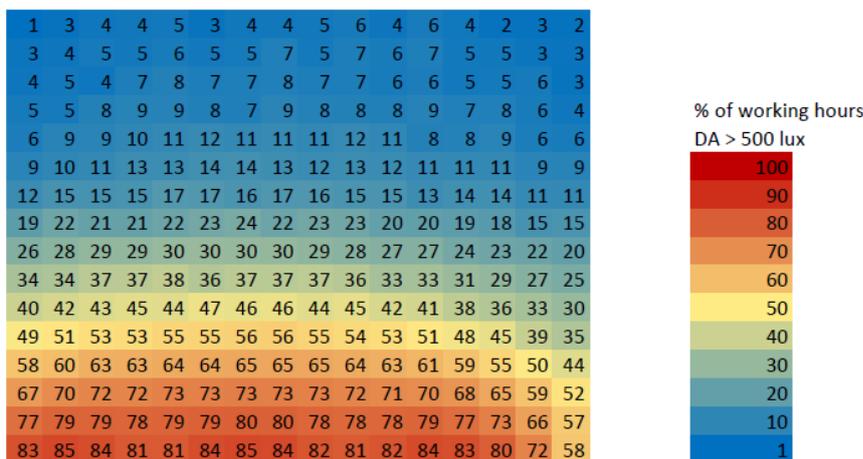


Figure 29: Dynamic Daylight Autonomy for the refurbished case-study (IES-VE)

Daylight Autonomy 500 lux (DA) (%):

Max: 85%
 Mean: 32%
 Min: 1%

DIVA for Rhino

Source: M.-C. Dubois

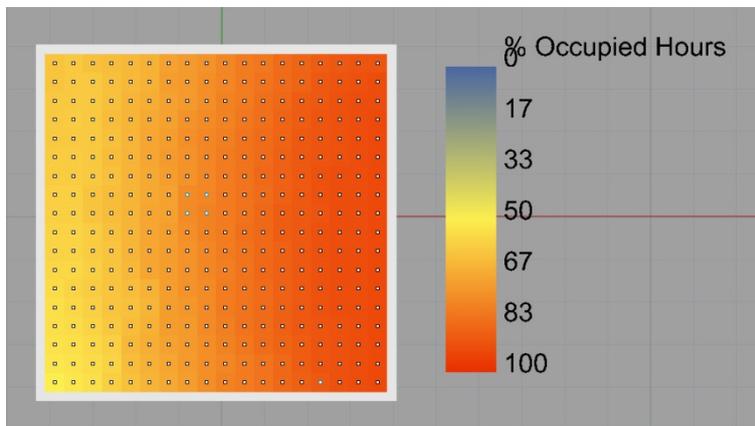


Figure 30: Dynamic Daylight Autonomy for the refurbished case-study (DIVA for Rhino, source M.-C. Dubois)

Dynamic daylight autonomy (DA) (%): 300 lux
 Max: 93%
 Mean: 70%
 Min: 50%

4.1.3. Useful Daylight Illuminance (UDI)

IES-VE

Source: M. Jørgensen

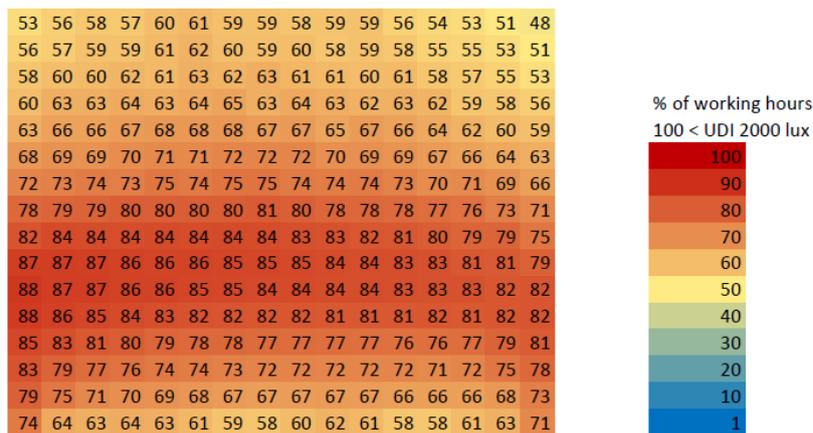


Figure 31: Useful Daylight Illuminance for the refurbished case-study (IES-VE, source M. Jørgensen)

Useful daylight illuminance 500 lux (DA) (%):
 Max: 88%
 Mean: 71%
 Min: 48%

4.1.4. Continuous daylight Autonomy (DAcon)

Daysim

Source: M. Bodart

- Target illuminance Level: 300 lux
- Occupation time: 8am - 5pm,
- Holidays From July to August,
- Weekend: Saturday and Sunday
- Sensor: centre of the room

Mean value: 87 %

4.1.5. Maximum Daylight Autonomy (DAm_{ax})

Daysim

Source: M. Bodart

- Target illuminance Level: 300 lux
- (Max. level = 3000 lux)
- Occupation time: 8am - 5pm,
- Holidays From July to August,
- Weekend: Saturday and Sunday
- Sensor: centre of the room

Mean value: 10 %

4.1.6. Spatial Daylight Autonomy

FENER

Source: B. Bueno

INITIAL SITUATION

Max: 92.4 %
Mean: 86.5 %
Min: 71.7 %
sDA_(300,50%) = 100 %

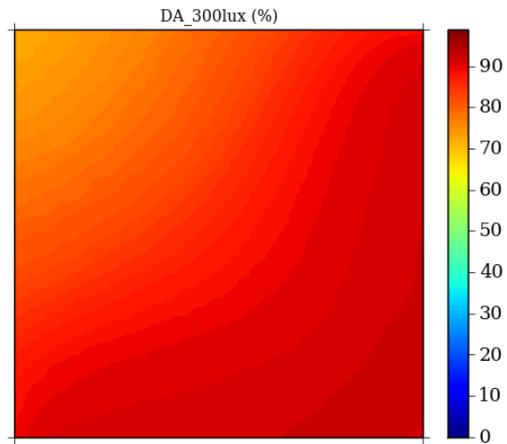


Figure 32: Spatial Daylight Autonomy for the case-study initial situation

AFTER REFURBISHMENT

Max: 91.5 %
Mean: 70.5 %
Min: 39.1 %
sDA_(300,50%) = 87.1 %

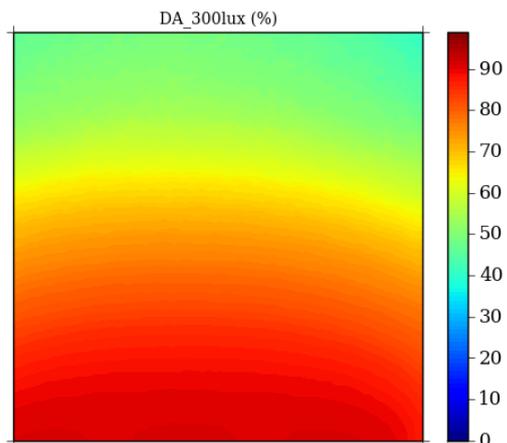


Figure 33: Spatial Daylight Autonomy for the case-study refurbished situation

Radiance

Source: D. Geisler Moroder

sDA_{300,50%} = 57.8%
 (July and August not considered)

“classical sDA”, i.e. all year,
 working hours 8am – 6pm:
sDA_{300,50%} = 64.8%

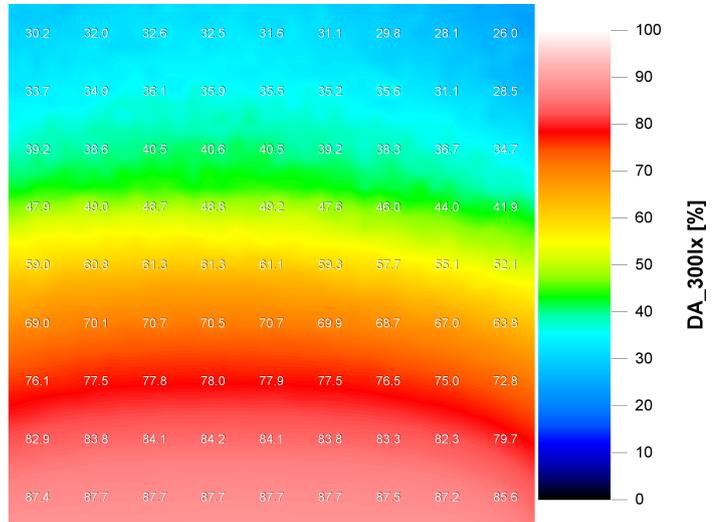


Figure 34: Spatial Daylight Autonomy (300 lux) for the refurbished case-study

4.1.7. Annual Sunlight Exposure

Radiance

Source: D. Geisler Moroder

$$ASE_{1000lx,250h} = 43.4\%$$

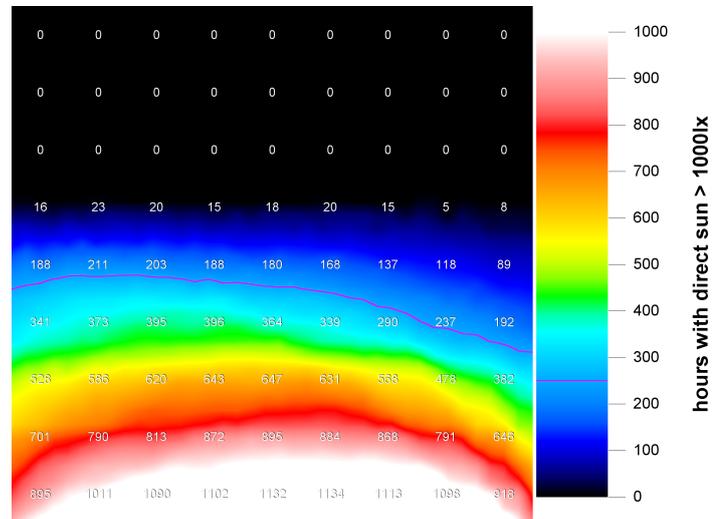


Figure 35: Annual sunlight Exposure for the refurbished case.

4.1.8. Daylight glare metrics

The images illustrate the situation of a CIE clear sky, on May 21st at 13h UTC + 1, with a view direction parallel to the glazed façade. The view-point is placed as shown below in **Erreur ! Source du renvoi introuvable..**

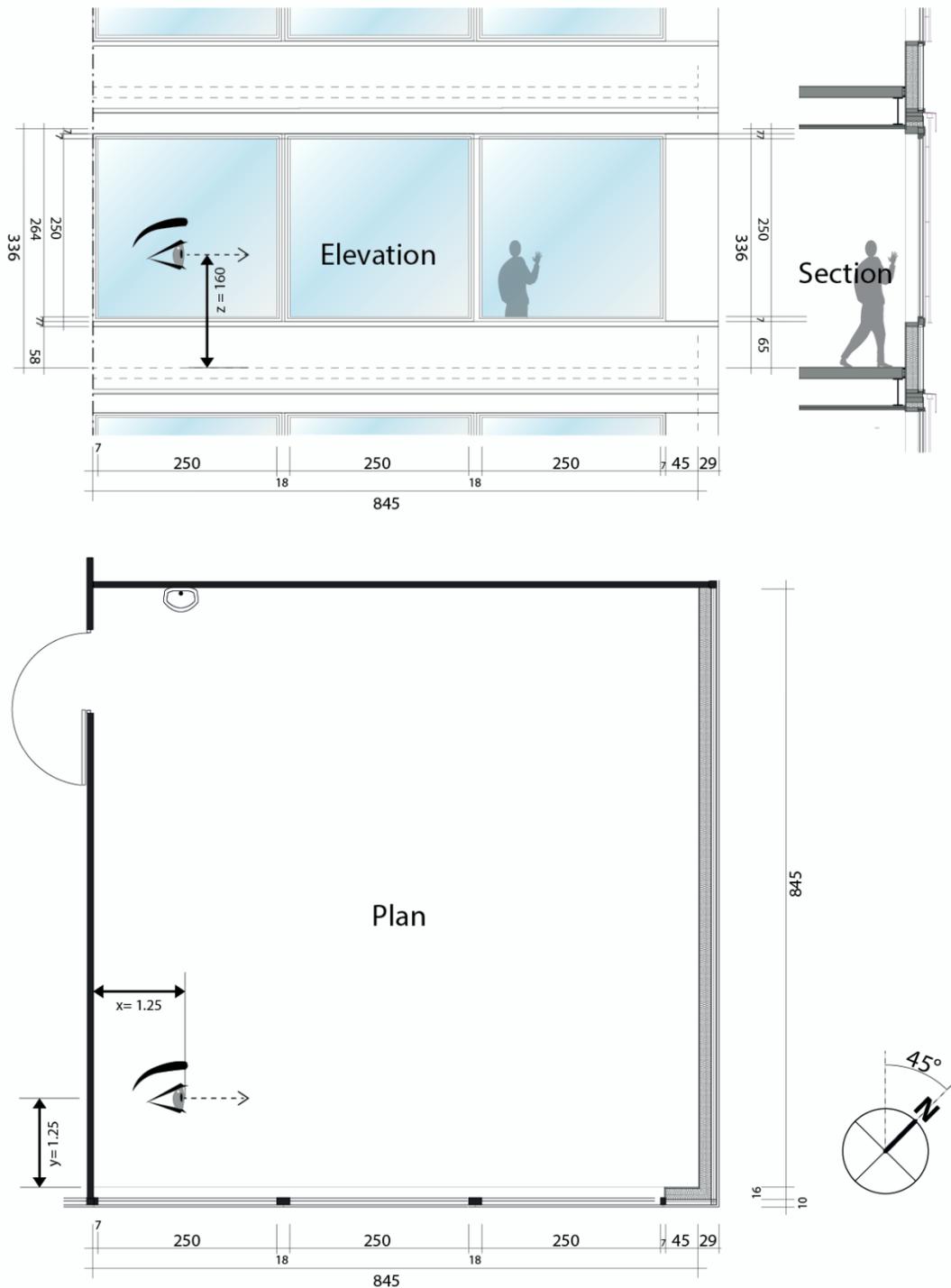
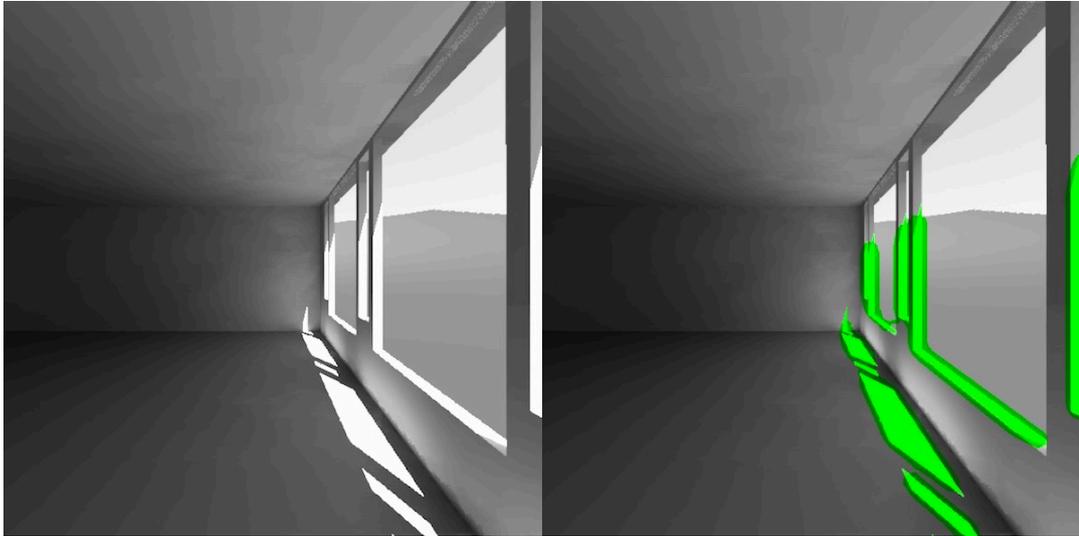


Figure 36: Description of the view-point used for glare simulations

DIAL+Lighting

Source B. PAULE / Estia SA

DGP = 0.31 (imperceptible) / DGI = 21.8 (just imperceptible)**Figure 37:** DIAL+ simulations, CIE clear sky, March 21st 13h UTC + 1, view direction parallel to the glazed façade***Geronimo***

Source J. Kaempf / LESO-PB - EPFL

DGP = 0.30 (imperceptible) / DGI = NA (just imperceptible)**Figure 38:** Geronimo simulations, CIE clear sky, March 21st 13h UTC + 1, view direction parallel to the glazed façade